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# Ecological Models for Assessing Functions of Hard Claypan Vernal Pool Wetlands in the Central Valley of California Using the Hydrogeomorphic (HGM) Approach for Wetland Assessment.

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**ECOLOGICAL MODELS FOR ASSESSING FUNCTIONS OF HARD CLAYPAN  
VERNAL POOL WETLANDS IN THE CENTRAL VALLEY OF CALIFORNIA  
USING THE HYDROGEOMORPHIC (HGM) APPROACH FOR WETLAND  
ASSESSMENT**

**A Dissertation**

**Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Doctor of Philosophy**

**in**

**The Department of Oceanography and Coastal Sciences**

**by**

**Ellis J. Clairain, Jr.**

**B.S., Louisiana State University, 1971**

**M.S., Louisiana State University, 1974**

**August 2000**

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## **ABSTRACT**

Seven vernal pool complexes consisting of numerous shallow wetland depressions were sampled in Sacramento County, California, during the spring and early summer of 1998. Data were obtained to characterize ecological conditions within each complex and to develop models for assessing wetland disturbance and functions.

Degree of disturbance, topographic features, soil profiles, and plant species composition and percent cover were examined. Pool area, volume, perimeter, maximum depth, distance from pool to pool, and percent of sample area were computed for 265 vernal pools. Additional detailed topographic and vegetative data were obtained at 68 vernal pools and soil profiles characterized at 64 vernal pools.

Disturbance was computed quantitatively by integrating the type of disturbance and proximity to the pool into a single numeric index. This disturbance quotient provided a relative measure of vernal pool alterations.

Data were analyzed using correlation analysis, stepwise discriminant analysis, and discriminant analysis to construct a model sensitive to disturbance. Results of the discriminant analysis indicated that three variables (disturbance quotient, maximum depth, and percent native to nonnative plant species) provided the best combination of factors to assess relative disturbance. A predictive model was developed using these three variables to accurately assign 92.8 percent of the pools to particular wetland areas indicative of different levels of alteration. Other variables that also related to disturbance included soil depth to the durapan and slope at the edge of the vernal pool.

Five wetland functions were identified as being relevant to vernal pools and ecological models were developed for each function. These models were calibrated with data collected from the vernal pools to provide a relative measure of the functional capacity of vernal pool wetlands in the Central Valley of California. The ecological models can be used to assess the capacity of wetlands to perform different functions, calculate project impacts on those functions, compute mitigation requirements to offset unavoidable impacts, and assess mitigation success.

## CHAPTER 1: INTRODUCTION

At the time of Colonial America, the area now consisting of the current 50 states contained approximately 159 million hectares of wetlands of which approximately 89 million were located in the lower 48 states (Dahl, 1990). During the 19th century, wetlands were considered a menace, the cause of malaria, a hindrance for land development, and areas where crop production was constrained (Office of Technology Assessment, 1984). Many national and local efforts supported conversion of wetlands to "more productive" land. Through the Swamp Land Acts of 1849, 1850, and 1860, Congress granted to states all swamps and overflow lands for reclamation to reduce destruction caused by flooding and to eliminate mosquito-breeding swamps (Shaw and Fredine, 1956). Consequently, over a period of 200 years from 1780 to 1980, the lower 48 states lost an estimated 53 percent of their original wetland area, or approximately 25 hectares of wetlands every hour this (Dahl, 1990). Annual wetland losses decreased from over 267,000 hectares per year during that 200-year period to approximately 117,000 hectares during the period 1974 to 1983 (Dahl and Johnson, 1991) and, although the rate of loss of wetlands has continued to decline, wetlands continue to be converted to other uses.

During the last two decades, however, there has been a growing awareness of the ecological, social, and economic benefits wetlands provide society (The Conservation Foundation, 1988). Wetlands have long been recognized as highly productive ecosystems, providing habitat functions for a wide variety of waterfowl, fur bearers, fish and invertebrate species. Wetlands also provide habitat for a disproportionately high number of endangered species (Mitsch and Gosselink, 1993).

Although wetlands encompass only about 3.5 percent of the land area of the lower 48 states, approximately 50 percent of the 209 endangered species listed in 1986 depended on wetlands for survival (Mitsch and Gosselink, 1993). However, during the last two decades studies have indicated that wetlands also provide numerous other functions important to society. Wetlands often trap sediments (Boto and Patrick, 1979) and heavy metals (Lee et al., 1978) and transform nutrients (Friedman and DeWitt, 1978; Van der Valk et al., 1978; Nixon and Lee, 1986), thereby improving water quality (Kibby, 1978). They also provide areas for water storage during flood events, impeding floodwaters and reducing flood damage (Dewey and Kropper Engineers, 1964; Carter et al. 1978; Novitzki, 1978; Verry and Boelter, 1978). Dense vegetation and root biomass in wetlands often provide a strong barrier from erosive forces in coastal wetlands and fringe wetlands along shorelines of large lakes and streams (Allen 1978; Dean, 1978). Wetlands have also been recognized for their visual-cultural values (Smardon, 1978; Niering, 1978).

Concurrent with the expanded scientific studies on wetlands was an increased public awareness of wetland functions (see the Glossary in Appendix A for definition of terms) and their values to society. Several laws were passed during the 1970's and 1980's, including the Federal Water Pollution Control Act Amendments of 1972, the Clean Water Act of 1977, the Threatened and Endangered Species Act, the National Environmental Policy Act of 1969, and state legislation and executive mandates such as Executive Order 11990 - Protection of Wetlands (42 U.S.C. 1977, pp. 4667-4669). Public attitudes shifted dramatically during this period from the concept of wetlands as wastelands to wetlands as important ecological and aesthetic features in the

landscape as illustrated in President Carter's statement that accompanied Executive Order 11990:

The Nation's coastal and inland wetlands are vital natural resources of critical importance to the people of this country. Wetlands are areas of great natural productivity, hydrological utility, and environmental diversity, providing natural flood control, improved water quality, recharge of aquifers, flow stabilization of streams and rivers, and habitat for fish and wildlife resources. Wetlands contribute to the production of agricultural products and timber and provide recreational, scientific, and esthetic resources of national interest. Executive Order 11990 orders each Federal agency to minimize the destruction, loss or degradation of wetlands, and to preserve and enhance the natural and beneficial values of wetlands in carrying out the agency's responsibilities.... Each agency shall avoid undertaking or providing assistance for new construction located in wetlands unless certain conditions are met. NEPA also requires consideration of project impacts, including those in wetlands. Therefore, all agencies have a mandate to protect wetlands as much as possible. However, the Order does not apply to the issuance by Federal agencies of permits, licenses, or allocations to private parties for activities involving wetlands on non-Federal property.

Section 404 of the Clean Water Act (33 U.S.C. 1344) directs the U.S. Army Corps of Engineers, in cooperation with the U.S. Environmental Protection Agency, to administer a regulatory program for permitting discharge of dredged and fill material into "waters of the United States," which, by definition, includes wetlands and other special aquatic sites. Applications for a permit to discharge dredged or fill material into waters of the United States must undergo a public interest review that includes assessing the impact of the proposed project on wetland functions and other factors related to the public interest. Results of the assessment are one of the factors considered in making the Section 404 permit decision.

The Corps was placed in a dilemma after passage of the Clean Water Act. It is required to complete permit processing expeditiously to avoid undue burden on the

public and provide consistent, repeatable results to avoid being arbitrary and capricious. Although a wide variety of techniques existed to assess wetland functions at that time (Larson, 1976; Reppert et al., 1979; Michigan Department of Natural Resources, 1980; and Lonard et al., 1981), none seemed to meet the requirements of the Corps. Several other methods were developed soon afterwards (U.S. Fish and Wildlife Service, 1980, 1981a, 1981b; Ammann et al., 1986; Adamus et al., 1987; World Wildlife Fund, 1992), but again, none effectively met the unique requirements of the Corps. The literature on wetland evaluation techniques at that time was diffuse and the state of our understanding of wetland functions was highly variable (Larson, 1982). A review by Lonard et al. (1981) of some of those early techniques revealed that many were designed to assess only select functions like providing wildlife habitat (U.S. Fish and Wildlife Service 1980; 1981a; 1981b) or focused on a particular wetland type like estuarine marshes or geographic area of the country like the glaciated northeast (Larson, 1976). However, no techniques were available (Lonard et al. 1981; U.S. Environmental Protection Agency, 1984; Bartoldus, 1999) that could rapidly assess a wide variety of wetland types and diverse wetland functions during any time of year. Nor were techniques available that could also provide consistent, repeatable results. These attributes are all requirements of the Corps of Engineers and many other Federal and state agencies.

These methods also could not address many of the basic programmatic or technical requirements of the Corps. Some of these requirements were identified by Reppert and Sigleo (1978). They continue today and are listed below. Any technique responsive to Corps needs should:

- Provide a standardized and documented approach to wetland assessment that can be applied in less than a day at any time of the year.
- Be applicable across the geographic extent of the Corps' regulatory jurisdiction.
- Provide consistent, repeatable results when applied at the same wetland by different regulatory staff.
- Apply to a variety of different wetland types.
- Be capable of assessing a variety of different wetland functions.
- Be sensitive to different types of impacts.
- Provide accuracy and precision consistent with the time and resources available to regulatory staff.
- Be adaptable to a variety of regulatory, management and planning applications.

The necessity for a rapid, technically sound, standard approach to wetland assessment with the ability to incorporate regional differences in wetland types and wetland functions was evident, but seemed a nearly impossible task. A national study plan was developed in 1983 (Clairain et al. 1985) and an interagency effort was initiated that same year (Sather and Clairain, 1985) to develop an effective wetland assessment technique.

### Objectives

This dissertation represents the effort to develop a regional guidebook for rapidly assessing wetland functions of hard claypan vernal pool wetlands in the Central Valley of California. These wetlands were once widely distributed throughout portions of Washington, Oregon, California, and portions of Mexico but now occur primarily on the coastal terraces and level topography of the lower coastal mountains and in the Central Valley of California. Because of their ephemeral nature and small size of individual pools, few attempts have been made to map vernal pools in California. Holland (1978) conducted one of the most rigorous mapping efforts (Figure 1).



The dissertation will provide the foundation for assessing project impacts in hard claypan vernal pool wetlands and for assessing mitigation alternatives. It will also provide a means to measure mitigation success if implemented over several sampling seasons.

More specific objectives of this study are to identify functions relevant to vernal pool wetlands, determine variables may be used to analyze those functions, and develop appropriate aggregations of variables into models to assess those functions in a format that can be quickly and efficiently performed in the field. The models are predicated on the assumption that the ability of a wetland to perform a variety of functions is reflected in the physical and biological characteristics of the wetland. By examining several characteristics in combination as models, and by establishing the range of characteristics between those wetlands that represent different levels of disturbance, one can assess the relative functioning of a wetland.

Although there has been a decline in wetland areas over the last two centuries, there has recently (during the last two decades) been a change in government perception of wetlands. Originally it was felt necessary to clear wetlands and convert them to agricultural production, leading to wetland losses. However, there has been a growing awareness of wetland functions and their values to society by the scientific and public communities, leading to several legislative mandates to examine projects that may have negative impacts on wetlands, and the necessity to develop techniques that can be used to assess wetland ecosystems. The Hydrogeomorphic (HGM) Approach is a consequence of this evolutionary process and thinking. What is the

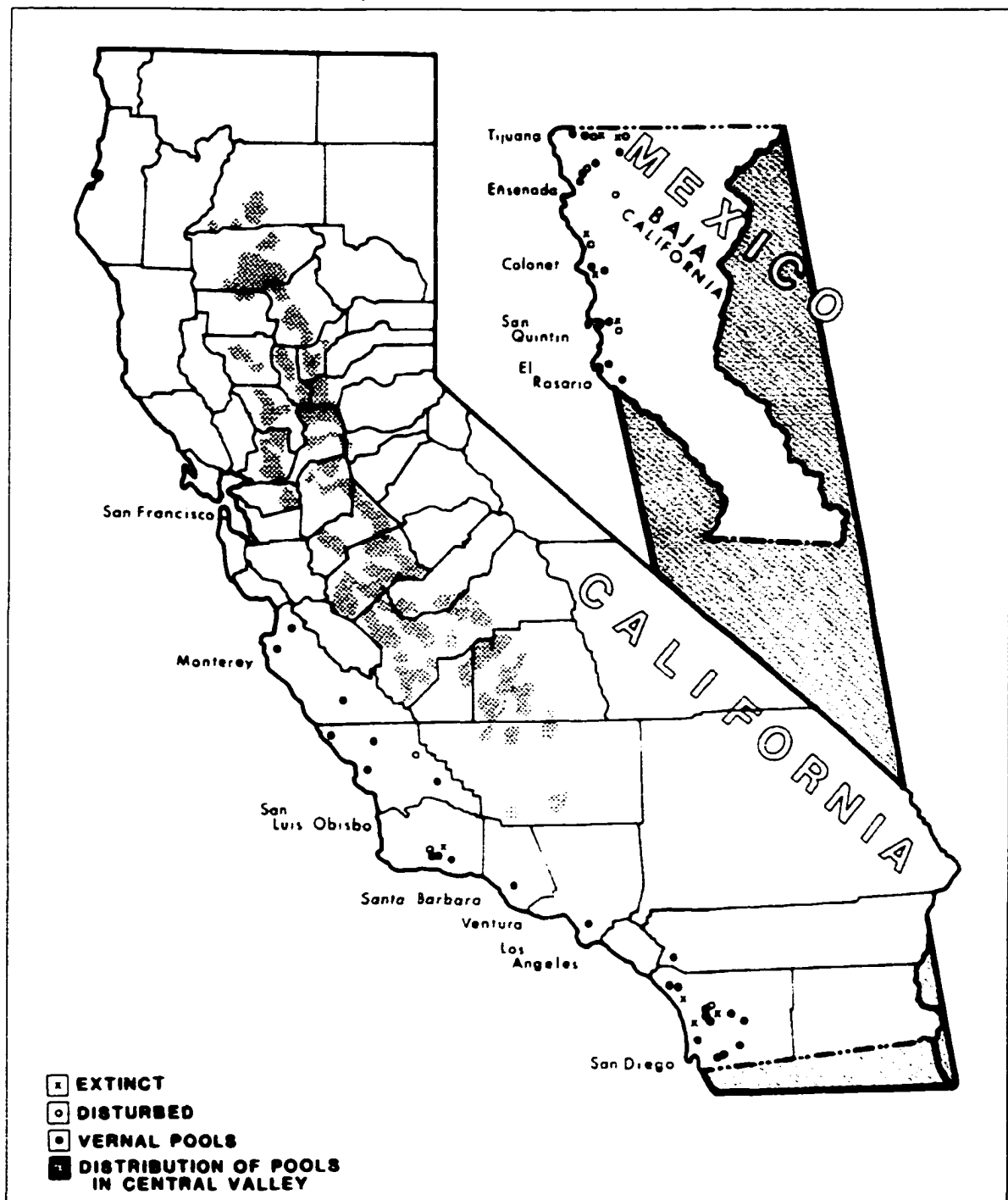


Figure 1. Distribution of vernal pools in California (Zedler 1987). Stippled areas represent vernal pools in the Central Valley as depicted in maps from Holland (1978). Other vernal pool locations are from Zedler (1987).

**HGM Approach? How is it different from other assessment techniques? How can regional efforts be developed? For answers to these questions and an overview of the HGM Approach to assessing wetland functions, the reader is referred to Chapter 2.**

**This dissertation is organized into several chapters. Chapter 1 provides an overview of the legal requirements for wetland protection, an indication of the magnitude of the problem (wetland losses) in spite of those legal requirements, a brief discussion of the tools to address the problems and their limitations, and the objectives of this dissertation. Chapter 2 presents an overview of a method under development (the HGM Approach) that is designed to address some of the limitations in prior wetland assessment techniques. Chapter 2 also illustrates how the HGM Approach is different from other methods. Chapter 3 describes methods used to collect data to facilitate implementation of the technique discussed in Chapter 2, and Chapter 4 describes vernal pool wetlands and field sites in the Central Valley of California where data were collected. Chapter 5 presents results of data collection and a discussion of the results. Chapter 6 provides a list of wetland functions for vernal pool wetlands and a set of ecological models or algorithms for each function. These models can be used to assess wetland functions, determine project impacts on wetland functions, and compute wetland mitigation requirements for unavoidable wetland impacts. Chapter 7 provides a short set of conclusions from the study.**

## **CHAPTER 2: OVERVIEW OF THE HYDROGEOMORPHIC (HGM) APPROACH**

### **Background**

In 1991 the Corps of Engineers expanded its Wetlands Research Program at the U.S. Army Engineer Waterways Experiment Station (WES) and its efforts to develop a wetland assessment technique that could meet the unique requirements of the Corps regulatory mission. The Hydrogeomorphic (HGM) Approach to Assessing Wetland Functions is the product of that effort. Although initially developed for Corps of Engineer regulatory needs, the HGM Approach can be applied to a wide variety of other uses that require examination of potential impacts on wetlands. It can also be used to assess effectiveness of mitigation plans, to compare conditions before and after project implementation, and to project future conditions with and without a project.

Basic concepts of the HGM Approach were developed during the first three years of the program and published in 1995 (Smith et al. 1995). A national guidebook was also prepared (Brinson et al. 1995) for riverine wetlands to serve as a template for developing region-specific guidebooks, which could then be used to conduct wetland assessments. An approach to classifying wetlands into similar classes was also developed (Brinson, 1993) to facilitate wetland assessments. However, efforts up until 1994, of necessity, focused on conceptual development of the HGM Approach with no products developed to implement the concepts. Those concepts, however, showed promise for developing a useful document that could be applied by all Federal agencies, and on August 24<sup>th</sup>, 1993, the White House Office on Environmental Policy released the Clinton Administration's comprehensive package of improvements to the

Federal wetlands program (White House Office on Environmental Policy, 1993).

This package stated that "The agencies will expedite development of a new approach for wetland functional assessment known as the Hydrogeomorphic Classification System (HGM)." It also stated that "The existing Executive Order on wetlands (E.O. 11990) will be revised to direct the Federal agencies to take a watershed/ecosystem approach to wetlands protection and restoration." (White House Office on Environmental Policy, 1993).

In response to the White House Office on Environmental Policy document, several Federal agencies that work closely with regulating, managing, or impacting wetlands formed a National Interagency Implementation Team (NIIT). The NIIT consists of representatives from the Corps of Engineers, including WES, the U.S. Environmental Protection Agency, the U.S. Department of Agriculture Natural Resources Conservation Service, the U.S. Fish and Wildlife Service, the Federal Highway Administration, and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service. NIIT developed a National Action Plan that provides a strategy the Corps and other Federal agencies will follow to implement the HGM Approach (*Federal Register*, 1996). The plan identifies the role each of the agencies will perform, provides quality control guidance for developing regional guidebooks to implement the HGM Approach, training and outreach, publication sequences, and assigns WES as the technical support center for development of the HGM Approach.

In 1994, efforts began to put the concepts into practice. Corps of Engineer District offices were contacted by personnel from WES and several Districts

volunteered to participate with WES in developing regional guidebooks. Corps Districts that volunteered and began implementing the concepts of the HGM Approach were: the Sacramento, Louisville, Omaha, and Jacksonville Districts and the New England Division. Working with staff from WES and other Federal and state agencies, personnel in these field offices began to grapple with conversion of concepts to tangible, applicable assessment documents. Small teams were formed and work began in late 1994.

### **What Is the HGM Approach?**

The HGM Approach for assessing wetland functions was developed from 1991 to 1999 by an interdisciplinary team of wetland scientists from Federal and state agencies and the academic community. Scientists at the U. S. Army Engineer Research and Development Center, Waterways Experiment Station (WES) provided leadership for HGM Approach development. The HGM Approach is a procedure that measures the capacity of a wetland to perform functions. It is designed to assess wetland ecosystems, which are normally characterized in terms of their structural components and the processes that link these components (Borman and Likens, 1969). Structural components of the ecosystem and the surrounding landscape (e.g., plants, soils, hydrology, and animals) interact with a variety of physical, chemical, and biological processes. Understanding the interactions of the structural components of the ecosystem with surrounding landscape features is the basis for assessing ecosystem functions and the foundation of the HGM Approach (Smith et al. 1995).

Wetland functions are the normal or characteristic activities that take place in wetland ecosystems (Smith et al. 1995). Wetlands perform a wide variety of wetland

functions. However, not all wetlands perform the same functions nor do similar wetlands perform the same function to the same level. The ability to perform a function is influenced by the characteristics of the wetland and the physical, chemical, and biological processes within the wetland. Wetland characteristics and processes influencing one function also often influence the performance of other functions within the same wetland ecosystem.

Wetland functions represent the currency or units of the wetland ecosystem for assessment purposes but the integrity of the ecosystem is not disconnected from each function, rather it represents the collective interaction of all wetland functions. Consequently, assessing wetlands with the HGM Approach requires that both those developing the assessment models and those applying the models recognize that the link between wetland functions and ecosystem integrity is critical. One cannot develop criteria, or models, to maximize a single function without having potentially negative impacts on the overall ecological integrity and sustainability of the whole wetland ecosystem. For example, one should not attempt to create a wetland to maximize water storage capacity without the recognition that other functions, such as plant species diversity, will likely be altered from those similar wetland types with less managed conditions. This does not mean that a wetland cannot be developed to maximize a particular function, but that it will typically not be a sustainable ecosystem without future human intervention, if at all.

### **How Is the HGM Approach Different from Other Assessment Methods?**

The HGM Approach is characterized and differentiated from other wetland assessment procedures in that it first classifies wetlands based on their ecological

characteristics (i.e., landscape setting, water source, and hydrodynamics). Second, it uses reference wetlands to establish the range of functioning of the wetlands. Third, it uses a relative index of function, calibrated to reference wetlands, to assess wetland functions. Each of these three characteristics is further discussed below.

### **Classification of Wetlands**

An early step in implementing the HGM Approach is to classify wetlands using procedures in Brinson (1993). Unlike procedures in Cowardin et al. (1979), which are designed largely to facilitate wetland mapping, the procedures in Brinson (1993) are designed to group wetlands into similar functional classes and subclasses. This classification is based on three fundamental factors that influence how wetlands function; (1) geomorphic setting, (2) water source, and (3) hydrodynamics.

Classification simplifies the assessment process by narrowing the range of assessment conditions. Wetlands are initially put into one of the following five classes: depressional, riverine, flat, slope, or fringe. Within a specific geographic area, wetland classes can be further subdivided into regional wetland subclasses (e.g., vernal pools in California, prairie potholes in the northern plains states, and pine flatwoods in the southeastern United States) (Table 1). Classifying wetlands based on how they function narrows the focus of attention to a specific type or subclass of wetland, the specific functions the subclass is most likely to perform, and the landscape and ecosystem factors that are most likely to influence how wetlands in the subclass function. This approach increases the accuracy of the assessment, allows for repeatability, and reduces the time needed to conduct the assessment.



**Table 1. Examples of wetland classes and subclasses with classification factors and characteristics using the wetland classification method by Brinson (1993).**

<b>Wetland Class and Geomorphic Setting</b>	<b>Wetland Subclass</b>	<b>Predominant Water Source</b>	<b>Hydrodynamics</b>	<b>Subclass Characteristics</b>
Depression	Vernal pools	Precipitation	Vertical fluctuations, low energy	Clay soils, durapan, Mediterranean climate
	Prairie potholes	Precipitation and/or Groundwater	Vertical fluctuations, low energy	Surface and groundwater, organic soils
Riverine	Low gradient	Runoff and groundwater	Unidirectional flow	Periodic high energy, overbank flow, fine soils
	High gradient	Runoff and groundwater	Unidirectional flow	High energy, lateral saturation, coarse textured soils
Slope	Intermontaine	Groundwater	Unidirectional flow	Organic soils in low energy environment
Flats	Pine flatwoods	Precipitation	Unidirectional flow	Mineral soils in low energy environment
	Discontinuous permafrost	Precipitation	Unidirectional flow	Low energy, organic soils
Fringe	Lacustrine	Precipitation and runoff	Bidirectional flow	Adjacent open water, sorted substrates
	Estuarine	Runoff and marine	Bidirectional flow	Low salt water and sorted substrates

The HGM Approach requires that one initially classify wetlands into five broad classes: depressions, riverine, slopes, flats, and fringe. These wetland classes are then further subdivided into regional subclasses based on other characteristics such as soils, slope, and vegetation.

Depression wetlands are located in a depression in the landscape so that the catchment area for the surface runoff is generally small (Brinson, 1993). Prairie potholes and vernal pools are examples of depression wetlands. Riverine wetlands form as linear features of the landscape with predominantly linear and periodic high

energy flows. The floodplain and watercourse of many streams represent the riverine class of wetlands in Brinson (1993) but represent the riverine (within bed and bank) and palustrine (floodplain) in Cowardin et al. (1979). Slope wetlands generally occur on the sides of hills or the toe of slopes and are predominantly groundwater fed, whereas flats usually occur in level terrain with precipitation as the primary water source. Fringe wetlands are located near large water bodies, most typically coastal environments or along large lakes, and receive frequent and regular two-way flow from astronomical tides or wind-driven water-level fluctuations (Brinson, 1993). Some examples of fringe wetlands are those along coastal areas or those adjacent to the Great Lakes.

This dissertation focuses on vernal pool wetlands that are shallow depressions underlain with an impermeable hard clay layer. The primary water source is from direct precipitation with very limited water received from adjacent runoff. Most of the vernal pools in this study were isolated, receiving very little direct inflow from or providing very little outflow to adjacent vernal pools. Therefore, vernal pool hydrodynamics are dominated by vertical fluctuations due to filling from direct precipitation and drying by evapotranspiration. For additional characterization of the vernal pools, see Chapter 4.

### **Use of Reference Wetlands**

Reference wetlands are wetland sites where data are gathered to scale assessment models. Reference standard wetlands are a subset of all the reference wetlands sampled and represent those sites considered to be the least disturbed and those that are ecologically stable or have reached climax succession. Reference

wetlands are selected from a reference domain (a defined geographic area) and represent the range of variability exhibited by a regional subclass as a result of natural processes and human perturbations (Smith et al. 1995). Using reference wetlands to scale the capacity of wetlands to perform a function is one of the unique features of the HGM Approach. Reference wetlands provide the standard for comparison in the HGM Approach. Unlike other methods that rely on data from published literature or best professional judgement, the HGM Approach requires identifying wetlands from the same regional subclass and from the same reference domain, collecting of data from those wetlands, and scaling of wetland variables to those data. Since wetlands exhibit a wide range of variability, reference wetlands should represent the range of conditions one might expect within the reference domain. A basic assumption of the HGM Approach is that the highest sustainable functional capacity is achieved in wetland ecosystems and landscapes that have not been subject to long-term anthropogenic disturbance (Smith et al. 1995). It is further assumed that under these conditions the structural components and physical, chemical, and biological processes within the wetland and surrounding landscape reach a dynamic equilibrium necessary to achieve the highest sustainable functional capacity. Reference standards are derived from these wetlands and used to calibrate variables. However, it is also necessary to recognize that many wetlands occur in less than standard conditions. Therefore, data must be collected from a wide range of disturbances in order to scale model variables from 0.0 to 1.0, the range used for each variable subindex.

The reference domain for vernal pools in this dissertation is Sacramento County in the Central Valley of California. However, the potential reference domain

is that area where similar wetlands occur and the models may apply, but where the vernal pools have not been sampled. The potential reference domain includes the Great Valley ecoregion of California (262A) (Figure 2) described by Miles and Goudey (1997). For additional information on the reference domain, see Chapter 4.

## **Functional Indices**

The HGM Approach uses functional indices based on multiple criteria assessment models (Smith and Theberge, 1987) to estimate the functional capacity of a wetland (Smith et al. 1995). The assessment models are simple representations of the relationship between the physical, chemical, and biological attributes of the wetland and surrounding landscape and the functional capacity of the wetland. Variables in the models are scaled to data obtained from the reference wetlands and assigned a subindex ranging from 0.0 to 1.0. Variables with attributes similar to those measured at reference standard sites or sites representing the least amount of disturbance and considered representative of some level of ecological integrity or climax are assigned an index of 1.0. As the variable deviates from the reference standard, the subindex is reduced from 1.0 to a low of 0.0 if the wetland cannot be restored and, therefore, the wetland's functional capacity is assumed to be zero. If a wetland has the potential for restoration, it is not assigned an index below 0.1. The rationale is to encourage use of "restorable" sites for mitigation instead of constructing wetlands for mitigation at sites that may have never been a wetland. Variables are aggregated into assessment models based on the experience of experts familiar with vernal pools and recommendations obtained during peer reviews.

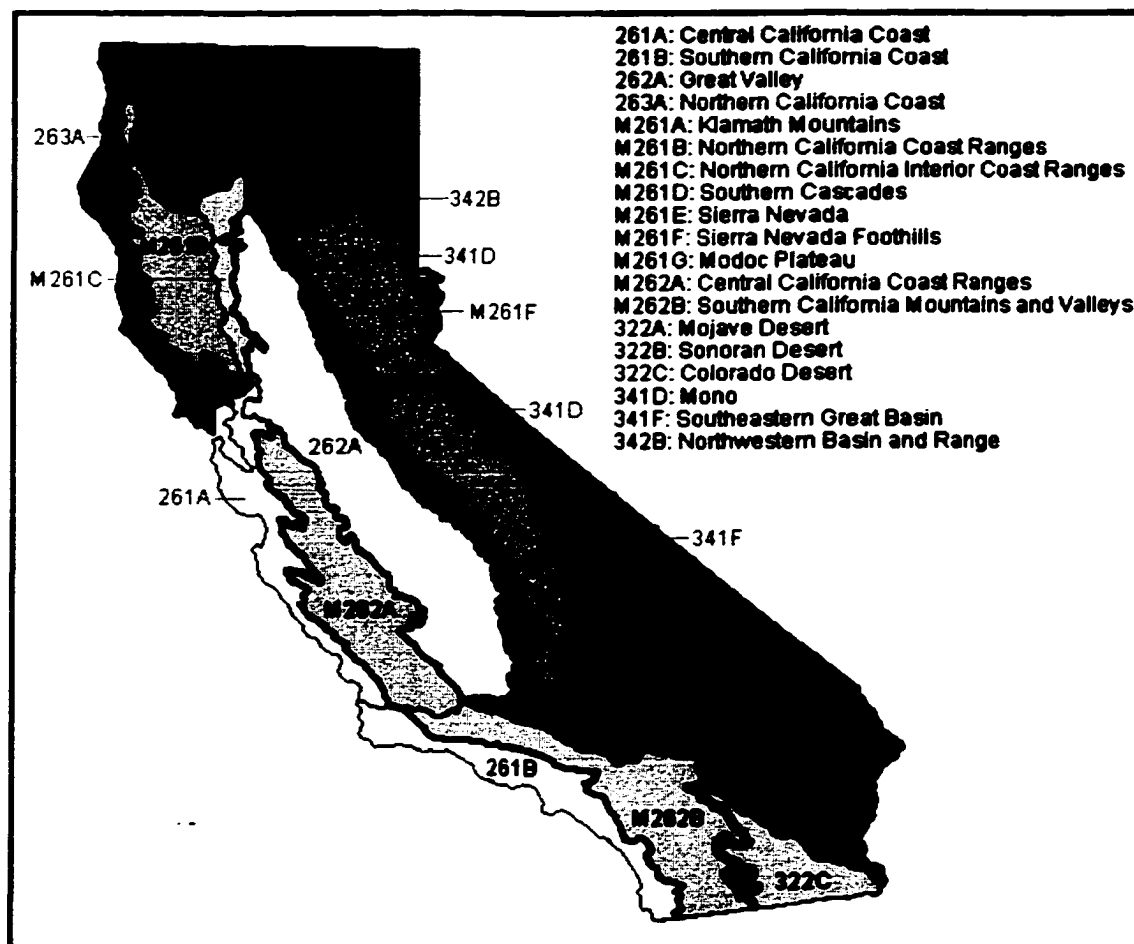


Figure 2. Ecological subregions of California (Miles and Goudey, 1997). Section 262A is the Great Valley and represents the potential reference domain where the assessment models in this dissertation may apply.

A major component of this dissertation was collecting and analyzing data from wetlands subjected to many types of disturbances and developing and scaling models to reflect perturbations on wetlands. For additional information about the data collection, see Chapter 3.

### Phases of the HGM Approach

The HGM Approach is implemented in two phases, a Developmental Phase, in which regional guidebooks are developed, and an Application Phase, in which the regional guidebooks are applied. During the Developmental Phase, an interagency,

interdisciplinary team (A-Team) of wetland scientists characterize the regional wetland subclass for which the assessment models will be developed, usually based on the amount of regulatory permits associated with a wetland type. Once the wetland subclass has been determined, the A-Team will identify the functions relevant to the regional wetland subclass and the variables that characterize the functions. Draft models are then developed to reflect the perceived relationship of the variables for each function. A small workshop of regional wetland scientists is then held to review the functions, variables, and models. Upon completion of the review, data are gathered from wetlands of the same regional subclass, models are calibrated or scaled to the data, and published as a regional guidebook on the Internet. Although the Development Phase is considered completed at that time and the Application Phase begins, future revisions can occur requiring subsequent developmental modifications to the assessment models. However, after publication on the Internet, the regional guidebooks are used by Corps of Engineers regulatory staff, other Federal and state agency personnel, and by private consultants to assess wetland functions, determine project impacts, and evaluate wetland mitigation requirements and success.

This dissertation represents efforts to implement the Development Phase of the HGM Approach for vernal pool wetlands. It is limited to those vernal pools where data were collected and models were calibrated in Sacramento County, but has the potential for use in similar vernal pools within the Great Valley ecoregion of California (Figure 2). More specific information about each of these phases is provided in Appendix B.

## **Potential Uses and Limitations**

The HGM Approach does not replace the need for delineating a wetland boundary, preclude the sequencing process, or supercede the Section 404 (b)(1) Guidelines analysis or public interest review. The HGM Approach is a tool that can be used in the alternatives analysis and is expected to be used on those permit actions that warrant a functional assessment for determining wetland impacts. Regulators will be able to use this procedure to rapidly and accurately determine the level of environmental impacts of proposed projects, compare project alternatives, identify measures that would minimize environmental impacts, determine mitigation requirements, and establish criteria for measuring mitigation success. Models can be applied to assess pre-project conditions, determine impacts of project alternatives, and design mitigation options to minimize impacts of potential project scenarios. The models must be applied cautiously for project future conditions, however. Model results will only be accurate if anticipated future wetland conditions accurately reflect future conditions. Model results will be helpful in providing greater certainty in permit decisions and reducing time required for permit review, thus expediting decision-making.

As important as it is to know what the HGM Approach was designed to do, it is also important to know what it was *not* intended to do. The HGM Approach does not assign a value to wetland functions. Value represents the significance of wetland functions to society or to individuals, and often reflects local priorities or policy issues beyond the scope of the HGM Approach. The functional capacity indices resulting from the HGM Approach cannot be equated to the societal or economic value of that

wetland function. The functional capacity indices may be used in combination with other information, however, when assigning values to wetland functions in terms of economic or other value units as required by the public interest review process.

The HGM Approach is also not to be used to compare different subclasses of wetlands. Rather, results should only be used to compare wetlands from similar subclasses in the same reference domain. Only by obtaining detailed quantitative data (e.g., cubic meters of water storage or grams of carbon  $\text{m}^{-2} \text{yr}^{-1}$ ) can the functions of different wetland types be compared. However, the time and resources required to achieve such a comparison are beyond the scope of the public interest review process and the HGM Approach.

Results from the HGM Approach also cannot be used to assess cumulative impacts required in the public interest review process (33 CFR 320.4 (a) (3)). The HGM Approach is designed to assess wetlands at the ecosystem scale. Although this ecosystem scale of analysis requires consideration of certain characteristics in the surrounding landscape, the assessment is restricted to the wetland ecosystem. Assessing cumulative impacts requires considering of the relationship of one ecosystem to another and the potential influence of one on another at a landscape scale, not solely at an ecosystem scale. Results from the HGM Approach, however, might be used in conjunction with other procedures designed to examine impacts at a landscape scale such as those by Lee and Gosselink (1988), Leibowitz et al. (1992), and Gosselink et al. (1990).

Each task required to develop a regional guidebook for vernal pool wetlands is briefly described in Chapter 3. Chapter 3 also contains the particular methods of data



**collection and analysis that can be used to select variables sensitive to disturbances and later for construction of each assessment model.**

## **CHAPTER 3: MATERIALS AND METHODS**

Developing ecological models for a regional guidebook to assess the functions of hard claypan vernal pool wetlands required several separate, but often interrelated, tasks. These tasks are required for developing any regional guidebook based on the HGM Approach, as outlined in Clairain and Smith (in prep.). Specific tasks completed to develop this dissertation are described below.

### **Task I - Organize a Regional Assessment Team (A-Team)**

The objective of Task I is to create a technical team of experts responsible for the overall administration and technical accuracy of the regional guidebook. An assessment team (A-Team) was formed in the summer of 1995 to develop a regional guidebook for vernal pools in California. The A-Team consisted of representatives from the Corps of Engineers Waterways Experiment Station, Corps of Engineers Sacramento District, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, USDA Natural Resources Conservation Service, California Department of Transportation, and the California Native Plant Society.

### **Task II - Identify and Prioritize Regional Wetland Subclasses**

Task II is designed to focus the regional guidebook to a particular type of wetland by identifying the different types within wetland subclasses. The A-Team prioritized the wetland subclasses, identified the geographic extent of each wetland subclass, and initiated a literature review. Priorities are typically somewhat predetermined by the needs of the regulatory agencies and developmental pressures on different wetland types that have often prompted the formation of the A-Team in the first place.

The A-Team met frequently during the spring and summer of 1996 and quickly focused on vernal pool wetlands because of the intense developmental pressures occurring in vernal pool complexes within the Corps' Sacramento District. Several types of vernal pool wetlands occur in the District, including those formed on lava flows and those with cemented soil horizons. However, most of the permit load in vernal pools seemed to focus on those with hard claypans, so that subclass of vernal pools was selected for developing the regional guidebook. The reference domain was restricted to the area immediately around Sacramento in Sacramento County in order to narrow the range of variability the A-Team anticipated may occur throughout the entire geographic extent of hard claypan vernal pools. Although the reference domain was narrowly focused to simplify model development and data collection, the A-Team felt that once the models were developed, they could be applied over a much broader area within the same ecoregion. The A-Team also identified the types of disturbances expected to occur within the hard claypan vernal pools so that future field sites could be selected to capture the range of disturbances.

### **Task III - Construct the Conceptual Assessment Models**

Potential wetland functions relevant to hard claypan vernal pool wetlands were identified and associated variables selected. Following selection of the wetland subclass and the reference domain, the A-Team and this author developed conceptual models for each wetland function. Conceptual models were prepared during the fall and winter of 1995 to reflect the perceived relationship of the model variables to wetland functions.

#### **Task IV - Peer Review of Draft Models and Variables**

Draft models received some limited technical reviews by scientists who were not on the A-Team periodically during the winter of 1995. However, a more thorough review was performed at a workshop held May 21-24, 1996 in Davis, California. The workshop was intended to expand the level of technical review and the technical level of reviewers. A contractor was selected to facilitate the workshop and summarize the recommendations. Participants had technical expertise and experience working in vernal pool wetlands and provided knowledge in one or more of the disciplines of hydrology, biogeochemistry, plant ecology, and wildlife ecology. The workshop agenda and a list of workshop participants is provided in Appendix C. Another objective of the workshop was to obtain recommendations for additional literature and to identify potential field sites for reference wetlands, particularly reference standard wetland sites.

Workshop participants were divided into small groups representing different technical disciplines and were requested to review the conceptual models and recommend revisions in the functions, variables, and model aggregations selected by the A-Team. Each work group had a facilitator and a recorder. Upon completion of the workshop, the A-Team examined workshop recommendations and revised the conceptual models.

#### **Task V - Calibrate and Field Test Assessment Models**

Variables and models were revised based on recommendations by workshop participants. Selection of field sites for data gathering and model calibration was initiated using recommendations from workshop participants and other sources of

information available to the A-Team. Several separate, but related components of the study were required to calibrate and field test the assessment models. Procedures were necessary for selection of study sites, selection of individual vernal pools within field sites, calculation of the degree of disturbance for each pool, determination of physical attributes of each pool and surrounding landscape features, collection of vegetation and soil characteristics, and analysis of data once collected.

### **Selection of Study Sites**

Study sites (vernal pool complexes) were limited to Sacramento County to reduce geographic variability. Sites were also limited to those having vernal pools underlain by an impervious clay layer, since several different types of vernal pools occur within Sacramento County. Most of the potential study sites were located on private land and since Federal regulatory agencies, particularly the Corps of Engineers (CE), are viewed with a high degree of cynicism, access was often limited. Vernal pool complexes where CE permit actions had previously been permitted (e.g., mitigation sites, or sites that were soon to be significantly altered) or sites in public ownership provided the primary sources from which to select sites for research. From this population, seven vernal pool complexes were selected for data collection and model calibration (Figure 3).

Sites were selected to represent a wide range of environmental conditions from areas having very little disturbance to extensively disturbed sites. Sites with those types of disturbances often considered in CE regulatory decisions were particularly sought. Table 3 lists the types of disturbances used to characterize each vernal pool complex and individual pool. Each disturbance subindex represents a

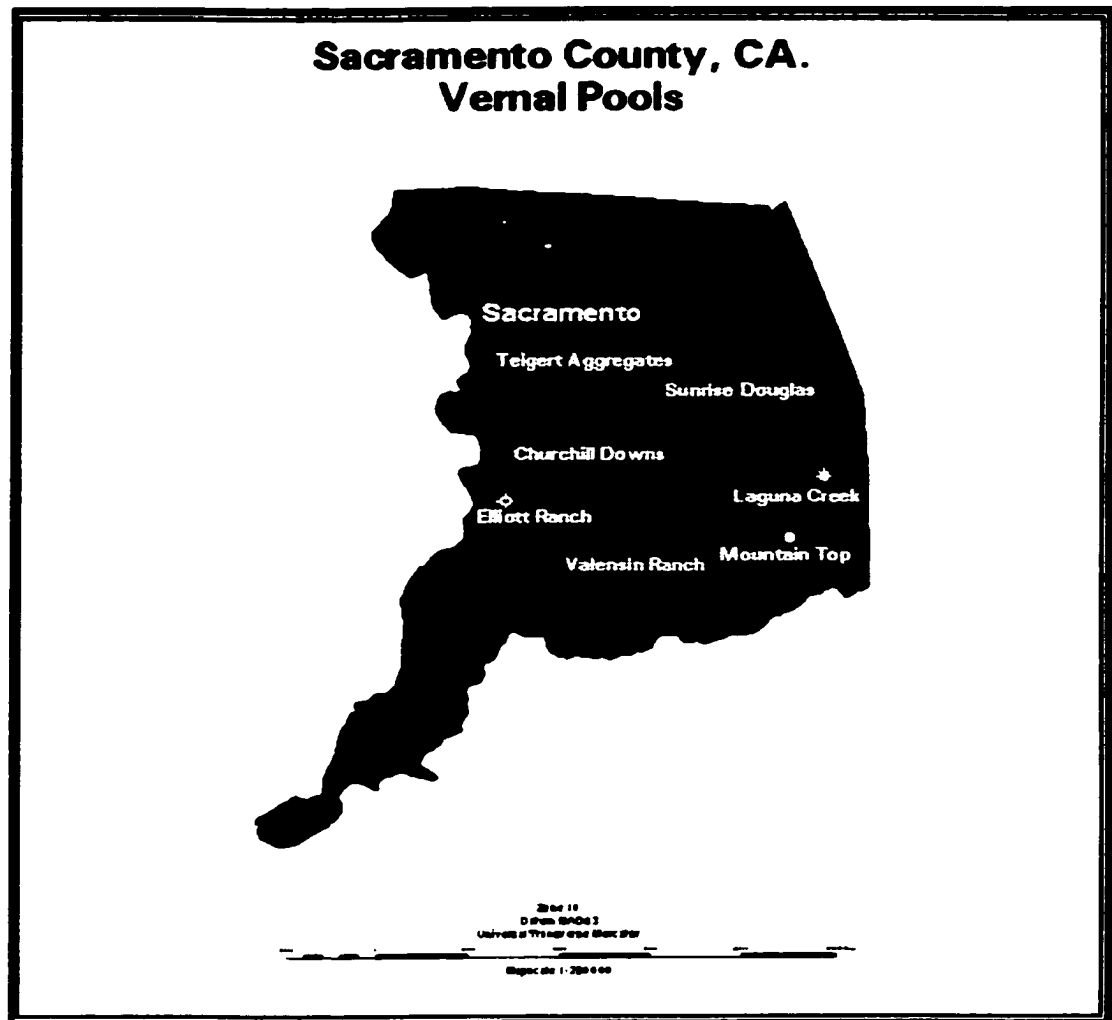


Figure 3. Locations of all vernal pool complexes sampled near Sacramento, California.

relative measure of the degree of disturbance one may anticipate for each activity. Therefore, no (none) disturbance is typically assigned a disturbance subindex of 1.0, meaning that under conditions of no disturbance, one would expect the vernal pool to be fully functional. One exception to this rationale is the subindex for grazing intensity. Range management practices suggest that vernal pools have evolved in an environment in which large undulates often occurred in the landscape. When a vernal pool complex does not have some light grazing, excess decomposed plant materials

Table 3. Types of disturbance factors expected in vernal pools in Sacramento County, California, and assigned disturbance subindices.

<b>DISTURBANCE FACTORS</b>	<b>DISTURBANCE SUBINDEX</b>
<b>AGRICULTURE</b>	
<b>CHEMICAL SPRAYING</b>	
None	1.00
Within one km but out of complex	0.75
Within the vernal pool complex	0.10
<b>TILLAGE</b>	
None	1.00
Harrowing	0.75
Mowing	0.75
Chiseling/disking	0.50
Plowing	0.25
Deep plowing – restoration possible	0.10
Deep ripping and leveling	0.00
Land leveling	0.25
<b>GRAZING</b>	
None	0.75
Light	1.00
Moderate	0.50
Severe	0.10
<b>SPECIAL MGT. PRACTICES</b>	1.0 or 0.0
<b>DEVELOPMENT</b>	
<b>RESIDENTIAL/COMMERCIAL: NONE</b>	1.00
Low-density residential	0.50
High-density residential	0.25
Low-density commercial	0.50
High-density commercial	0.25
<b>PUBLIC ACCESS</b>	
None	1.00
Limited	0.75
Open w/ disturbance	0.50
<b>HYDROLOGIC MODIFICATIONS</b>	
None	1.00
Interceptions of inflows	0.10
Diversions of flows away	0.10

tend to change the soil thermal properties and textural characteristics, often resulting in a shift in plant composition away from one dominated by native species.

Therefore, light grazing was assigned a disturbance subindex of 1.0 and no grazing a subindex of 0.75. For additional information about the disturbance assessment, see “Calculation of Disturbance” later in this chapter. Sites that had received very limited disturbance were also included and provided a reference standard to which data from disturbed sites could be compared. Valensin Ranch was considered the best example of a relatively undisturbed vernal pool complex based on knowledge of several local citizens familiar with vernal pools in the Sacramento area. The Nature Conservancy, a nonprofit conservation group, and the State of California own Valensin Ranch.

Access is controlled with a fence and gate, but the site was available for research.

Conversely, the site at Mountain Top represented the most disturbed of the field sites.

A Section 404 permit had been issued several months prior to the period planned for sampling so the landowner was willing to allow data collection at the site. At the time of data collection, the site was being converted from an existing vernal pool complex to a vineyard for future grape and wine production. The substrate had been deep-ripped by heavy equipment to a depth of approximately two meters in two directions to break the underlying hard claypan and enhance internal drainage. Deep-ripping or subsoiling of the substrate occurred several months prior to data collection at the site.

An irrigation system was also under development at the time of data collection.

Figure 4 (a) illustrates site conditions at Mountain Top during data collection and

Figure 4 (b) illustrates site conditions with the planted vineyard in place approximately six months after data collection.



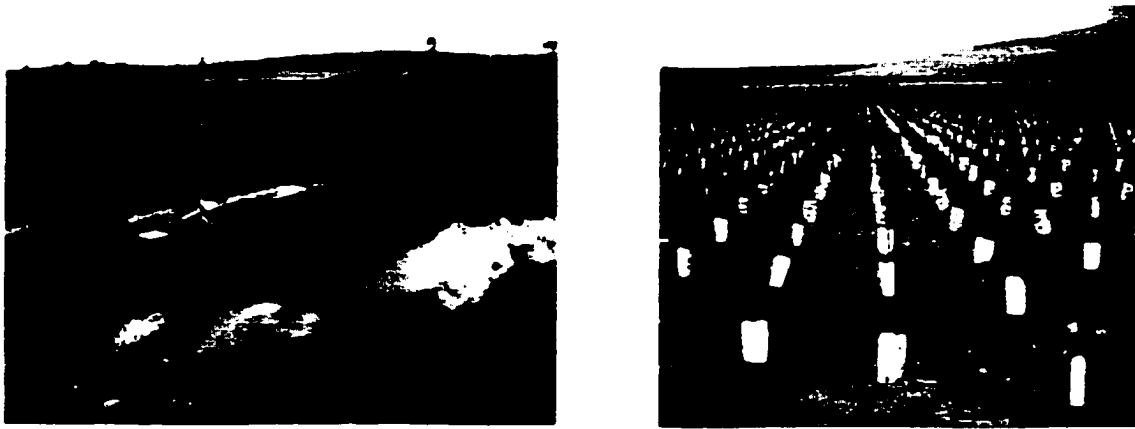


Figure 4. Mountain Top during data collection (a) April 24, 1998 and October 15, 1998 (b).

Although vernal pool complexes were selected to represent a range of disturbances, they were also selected based on their consistency in representing those pools that typically are underlain by a hard claypan. Vernal pools formed from historic lava flows or due to basalt formation were excluded from this study. Other site selection criteria included availability of aerial coverage, accessibility to field personnel, or the existence of prior studies.

### Selection of Sample Areas within Study Sites

Most of the seven vernal pool complexes encompassed many hectares, so it was necessary to select a subset of the entire complex for more detailed analysis. After examining aerial photos and other available maps of each complex, an area 125 meters wide and of varying length ranging from 250 to 350 meters was selected. The size and shape of the vernal pool complex influenced the length of each sample area selected. Sample area locations were positioned to provide a representative sample of the vernal pool complex. At three of the seven study sites, Sunrise Douglas, Churchill

Downs, and Laguna Creek, two sample areas were established. Therefore, 10 sample areas were established for intensive study and sampling.

Once the sample area locations were identified from aerial photography and office data, a survey crew established two temporary benchmarks at each sample area. Using a Trimble GPS Pathfinder®, Model Pro XL on a permanent benchmark and a Trimble GeoExplorer® II as a roving station, temporary benchmarks were established at each of the seven field sites. The GeoExplorer® II was placed at the location of each temporary benchmark and data were recorded for 10 minutes to allow correction of the satellite data and provide accuracy of  $\pm 1.0$  meter resolution in the x, y, and z coordinates for the temporary benchmark locations. Then using a Leica® Total Station Model TCA1500 with robotics capability and a 360° prism, elevations were obtained within a resolution less than one centimeter relative to the elevation of the temporary benchmark. Elevation data were obtained during May, June, and October 1998. Corners and borders were established with the survey equipment and every vernal pool was surveyed. Survey points were collected along the edge of every vernal pool to represent the pool morphology. Corps of Engineer staff from the Sacramento District delineated vernal pool boundaries. Delineations followed procedures outlined in the 1987 Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987). Points were also obtained within each pool and at locations outside of each pool to facilitate development of a topographic map for each sample area. The topographic survey was later refined at five of the sites by attaching a 360° prism to an ATV (Figure 5) and traversing the length of each sample area

along transects 25 meters apart for a total of seven transects (one on each side and five in between). Elevation points were collected at 5-second intervals along each survey



Figure 5. Field equipment used to obtain topographic data included a Leica® total station mounted on a tripod and a 360° mirror mounted on an ATV, and a notebook computer to continuously record data from the total station.

transect and recorded in a computer program developed by personnel at the U.S.

Army Engineer Research and Development Center, Waterways Experiment Station.

### **Selection of Individual Vernal Pools within Each Sample Area**

Topographic data were processed using ArcInfo® to prepare maps of each sample area. These maps illustrated topographic features and vernal pool sizes and interconnectedness. When individual vernal pools were connected by shallow swales, the survey points were also collected at the edge of each swale and within the swale. Using the maps, individual pools were selected to represent a variety of sizes and classified as isolated or connected, natural or constructed. Pools were also selected to

represent different topographic features and soil characteristics. Each selected vernal pool was then sampled in greater detail for vegetative characteristics, topographic features, and soil characteristics during the spring and early summer of 1998.

### **Vegetation Sampling**

Once individual vernal pools were selected based on the initial topographic survey discussed above, two transects were established within and immediately outside each pool. The origin of each transect was established at the lowest or deepest point of the pool based on visual inspection. One transect was then established from the origin along the longest axis of the pool to approximately two meters outside of the pool to determine species composition outside of the pool and to indicate the change in species composition between the pool and mimia mound. Another transect was established from the origin along the shortest distance to the edge of the pool and also approximately two meters past the edge of the pool. Small survey flags were placed at the origin, pool edge, and at the end of each transect to facilitate subsequent data collection for vegetation and soils and for additional survey data collection. To avoid tramping vegetation, transect layout was always performed by working on the right side of each transect when standing at the origin of each transect and looking along the transect toward the edge of the pool. Data collection was then always performed on the left side of each transect.

Percent cover of each species was obtained within 20-cm by 50-cm quadrats laid along each transect at one-meter intervals. A 50-meter tape was anchored to the origin of each transect and laid along the bottom of the pool to the flag at the end of each transect. Using the measuring tape as a guide for quadrat placement, the percent

cover of each species found within each quadrat was estimated at one-meter intervals. The percent of bare ground, surface water area, and presence of any algal mat formation were also noted within each quadrat using the percent cover classes by Daubenmire (1959; 1968). Plant species were identified using local botanists from the Sacramento District. During data collection, general observations of invertebrate occurrence (e.g., direct observations when pools were flooded and presence of carapace remains after drying) and other animal signs were also noted.

### Soil Sampling

Soil samples were collected during the spring and early summer of 1998. Data were collected near the deepest point within each pool and at the end of the longest transect outside the pool. Consequently, two soil profiles were sampled per pool. Mr. Glenn Stanisewski, soils scientist with the USDA Natural Resources Conservation Service in Davis, California, and Dr. Steven Sprecher, soils scientist at WES, collected the soil profile data.

The landform and geomorphic surface were noted at each pool and a hole was dug with a spade. Soil characteristics for each soil horizon were compared to those expected from the Soil Survey of Sacramento County (Tugel et al. 1993). Each soil horizon was described, depth noted, soil texture identified, and available water capacity computed at each soil pit. Also noted was the presence or absence of a restricting layer and its depth in centimeters recorded, if present. Any indication of soil compaction or tillage and erosion or sedimentation was also noted at the profile within the pool.

## **Individual Vernal Pool Topography**

**In addition to collecting percent cover of vegetation within each sample plot along each transect, the elevation of each plot was determined using survey equipment similar to that used for the initial topographic survey. Data from these elevation points were later processed using ArcInfo® software to further refine the topographic mapping of each pool sampled. Additional variables computed from the elevation data include the following: elevation and depth of each vegetation plot, maximum depth of each pool, size and perimeter of each pool, distance to nearest pool from pool edge to edge and centroid to centroid, volume, and the average and minimum elevation of the edge of the pool (necessary to calculate depths and volumes).**

**Volumes were calculated using a computer program developed by personnel at WES. The program establishes one-meter grid cells across the vernal pool and computes the depth of each cell from the topographic data. The area of each grid cell along the edge of each pool is computed when less than one square meter and volume is computed for those cells. The total volume of each pool is then computed by adding the volumes for all the cells.**

**The slope for each of four segments of each transect of each pool was computed using the survey data. Distance from the origin of each transect to the edge of each pool was divided into three segments and slopes were computed for each. The slope of the fourth segment was computed from the edge of the pool to the end of the transect outside of the pool.**

## **Calculation of Disturbance**

Since models developed in this dissertation are designed to represent a relative measure of wetland disturbance and hence a measure of the functional capacity of the wetland, a process was developed to quantitatively represent the relative disturbance of each pool sampled for vegetation in order to scale the models. The procedure, in itself, could not replace the assessment models since it cannot provide insightful information on wetland functioning or facilitate determination of mitigation requirements or mitigation design.

Several components of disturbance were considered in computing a disturbance quotient for each pool. One component considered was the type of disturbance and possible severity of that disturbance on the functional capacity of the vernal pool. Another component was the proximity of the disturbance to the pool. The final component was the amount of disturbance distributed around the pool. A list of the types of disturbances likely to occur in vernal pools in the Sacramento area was developed (Table 2) with input from wetland experts from near Sacramento based on their experience in wetland regulatory issues. Several broad categories of disturbance were identified including those resulting from agricultural practices, urban and commercial development, and from hydrologic alterations from excavation or draining vernal pools. Each category was further subdivided into other, more specific activities and a relative index ranging from 0.0 to 1.0 was assigned to each type of activity. Those activities that were assumed to have no influence on wetland functional capacity were assigned a 1.0, whereas those assumed to have severe influence on the integrity of the wetland were assigned a 0.0.

Once a relative index of disturbance was developed for each anticipated developmental action, data were collected for each vernal pool where vegetative data were to be collected. Beginning at the origin of each transect discussed above for surveying and vegetative sampling, eight sectors were established at 45 degrees starting north of the origin (Figure 6). Within each sector, each type of disturbance was identified. It was noted whether the disturbance occurred within the pool,

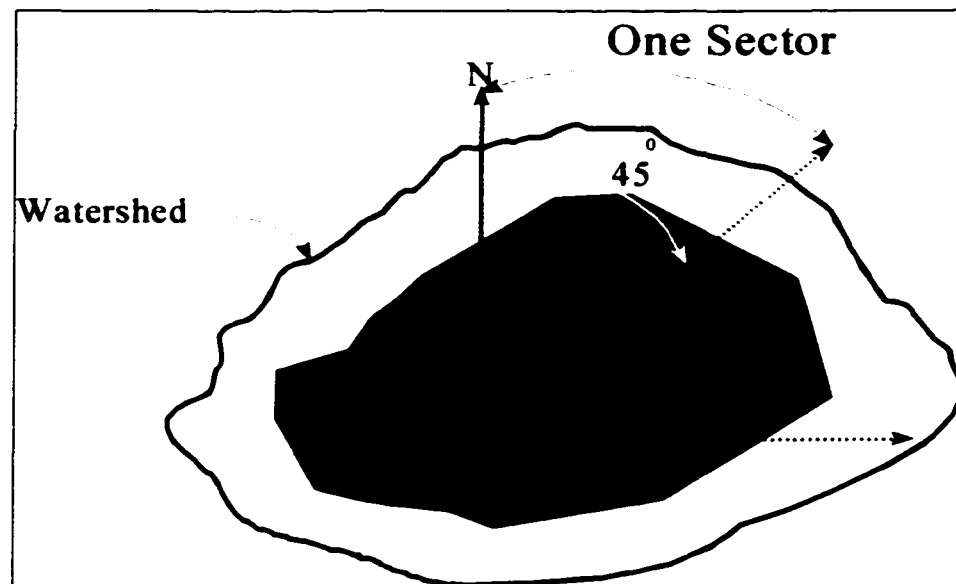


Figure 6. Data collection layout for determining the disturbance quotient of each vernal pool. Disturbances were identified within each of the eight 45° sectors.

within the watershed of the pool but outside of the pool, or outside of the watershed but within one kilometer of the pool. For those disturbances outside of the pool but within the watershed, the distance to the edge of the pool was noted in meters. An equation (Disturbance Quotient Equation below) was developed that considered the three levels of proximity to the pool (inside the pool, outside but in the watershed, and outside the watershed but within one kilometer), the type of disturbance, and the



frequency of occurrence around the vernal pool. Using one type of disturbance as an example, in a case where more than one type of disturbance was noted, the

### Disturbance Quotient Equation

$$DQ = \sum_{i=1}^n \frac{((3 \cdot I) + (2 \cdot W \cdot ((\text{SQRT}(1/(0.9999 + (D))) - 0.0001)))) + (K))}{8} / 6$$

where:

- $DQ$  = disturbance quotient for one pool
- $n$  =
- $\sum_{i=1}^n$  = summation of the disturbance components for sectors 1 to n
- $n$  = number of sectors where some type of disturbance is observed
- $I$  = disturbance index for the most severe type of disturbance occurring within the vernal pool for each sector
- $W$  = disturbance index for the most severe type of disturbance occurring within the watershed of the vernal pool for each sector
- $\text{SQRT}$  = square root
- $D$  = distance in meters from the edge of the vernal pool to the nearest most severe disturbance; anything less than one meter is zero (0), and then in whole numbers thereafter with 1 = 1 to <2 meters, 2 = 2 to < 3 meters, etc.
- $K$  = disturbance index for the most severe type of disturbance occurring within one kilometer of the outside edge of the vernal pool watershed for each sector

most severe disturbance subindex within the pool (most degrading disturbance is scored a 0.0) was assigned three times the weight of the disturbance outside of the watershed but within a kilometer. The most damaging disturbance within the watershed but outside the pool edge was assigned twice the weight of those outside of the watershed. In order to also account for the proximity of those disturbances outside of the pools but within the watershed, a decay function (inverse of the square

root of the distance from the edge) was multiplied by the disturbance subindex within the watershed. The product of the equation was a disturbance quotient that represented an integration of the relative severity of the disturbances and proximity to the pool. The equation provided a numeric score from 0.0 (totally destroyed pool) to 1.0 (relatively undisturbed), which could be used to rank each vernal pool along a relative disturbance gradient.

### **Analytical Procedures**

A suite of variables was identified during development of the conceptual models discussed above. However, data for numerous additional variables were collected as part of the calibration process. Therefore, the models were comprised of variables that exhibited some relationship to the disturbance factors and some variables that influenced wetland function. For example, the variable for the distance from the edge of one pool to the edge of the nearest pool was not determined to be related to disturbance. However, it is important in assessing the suitability of a pool to provide habitat for amphibians. Therefore, the variable was retained and incorporated into the appropriate model. For more details about model development, see Chapter 6.

A subset of 70 percent of all the vernal pools (48) was used to calibrate the models and the remaining 20 pools were used to test the calibrated models. Pools were selected at random for testing after stratifying the pools by sample area. Randomization was accomplished by selecting pools from a random numbers table using Microsoft Excel© software. Consequently, all sample sites were represented in the calibration data set and in the test data set.

Data were analyzed using two computer software packages. Vegetative data were initially prepared in the compact format using procedures for PC-ORD Version 4.0 (MjM Software Design 1999) for Windows. Ordination analysis of the vegetation data was accomplished using procedures in PC-ORD. The Statistical Analysis System (SAS Institute 1990) Version 6.12 for Windows was used for most of the other statistical analyses including regression analysis and summary statistics.

After completing model calibration in Task V, the models were tested using data from a holdout sample data set. Results were then compared to the original calibration data set.

## **CHAPTER 4: DESCRIPTION OF STUDY AREA**

### **What Is a Vernal Pool?**

#### **Definition**

Vernal pools occur in many areas of the United States and throughout the world. Some scientists have loosely referred to shallow, forested depressions in the northeastern United States as vernal pools. Flooded conditions may remain throughout the year with only occasional drying. Those vernal pools provide important habitat for many amphibian species. Vernal pools also occur throughout much of the Central Valley of California from north of Sacramento to San Diego. However, unlike vernal pools in the northeast, vernal pools in California are dominated by herbaceous vegetation and have a distinct seasonal wetting and drying cycle.

Vernal pools have been defined variously by scientists familiar with seasonally inundated wetlands in California and wetland scientists elsewhere. Lincoln et al. (1998) define a vernal pool as “a temporary pool formed during spring from meltwater or floodwater.” Although this definition could satisfy the term used in the northeastern United States, it is insufficient for California, because California’s vernal pools form during the winter and persist late into the spring. California’s vernal pools also develop almost entirely from direct precipitation and are not subjected to flooding from nearby streams or other water bodies. Zedler (1987) defines vernal pools in California as “a natural habitat of the Mediterranean climate region of the Pacific Coast covered by shallow water for extended periods during the cool season but completely dry for most of the warm season drought.”

## **Classification**

Using terminology in Cowardin et al. (1992), vernal pools would be classified as palustrine emergent wetlands with nonpersistent vegetation and a seasonally flooded water regime. Ferrin et al. (1995), following the classification by Cowardin et al. (1979), classified vernal pools for the central and southern California coast and coastal regions. Vernal pools were considered a subset of a diverse number of palustrine wetland types. The wetland classification procedures for the HGM Approach (Brinson 1995) would classify vernal pools at the class level as wetlands occurring in shallow depressions within the landscape and having a water source dominated by precipitation. The hydrodynamics would be typically low energy with vertical fluctuations. Earlier classifications of vernal pools were developed by Holstein (1984), Holland (1986), and Jones and Stokes and Associates, Inc. (1990).

Although vernal pools in California have some characteristics common to many other types of depression wetlands, they also have some attributes that make them rather unique among wetlands in the United States. Many of these attributes can be used to further subdivide wetland classes into the subclass level using Brinson (1993) classification for the HGM Approach. California vernal pools are dominated by herbaceous vegetation and only occur in those areas dominated by a Mediterranean climate. That significantly limits the geographic extent within the United States to the West Coast, predominantly to California, although vernal pools also occur in some areas of Oregon. The limitation of vernal pools to a Mediterranean climate results in a rather unusual seasonal pattern of wetting and drying, which leads to some rather unique plant and animal inhabitants, many endemic only to vernal pools. Vernal

pools are also only found where there is a perched water table, often as a consequence of high clay content in the soil. (Zedler 1987).

Vernal pools are also typically small, ranging from 50 m<sup>2</sup> to about 0.5 hectare (Mitsch and Gosselink 1993) but can often be even smaller. They are also typically shallow with depths often less than 30 cm. Vernal pools often have fairly level bottoms with the edges abruptly rising from the bottom, similar to a shallow bowl on the landscape. Individual pools are often isolated, but can occasionally be connected to adjacent pools by shallow swales during high-water periods. Vernal pools typically occur in complexes encompassing numerous vernal pools dispersed over many hectares.

Miles and Goudey (1997) list seven different vernal pool types in California, but four are defined by their location, all in Southern California. The three remaining types, Northern Claypan vernal pools, Northern mudflow vernal pools, and Northern basalt vernal pools are based on the origin of their confining substrates. Northern claypan vernal pools are the most widely distributed and represent the vernal pool regional subclass that is the subject of this dissertation.

### **Seasonal Phases of Vernal Pools**

Vernal pools typically undergo four distinct phases during each year (Zedler 1987). Seasonal wetting and drying characterize these phases and plant and soil characteristics change with the changes in wetting and drying (Table 3). The associated plant and animal communities also respond to this wetting and drying cycle. Each phase is briefly described below.

**Table 3. Seasonal phases of vernal pools including physical changes and biological responses during each phase.**

<b>Vernal Pool Phase</b>	<b>Season</b>	<b>Physical Characteristics</b>	<b>Biological Responses</b>
<b>Wetting</b>	<b>Fall (Oct – Dec)</b>	<b>Pools begin to fill, soils swell and seal cracks in pool basins</b>	<b>Dormant seeds begin to germinate, dense mat of seedlings begins to develop</b>
<b>Aquatic</b>	<b>Winter (Jan – early Mar)</b>	<b>Pools full</b>	<b>Aquatic plants abundant, invertebrates populate the pools, amphibians and avifauna use pools, algae often becomes abundant</b>
<b>Drying</b>	<b>Spring (late Mar – Apr)</b>	<b>Water levels decline, soils begin to dry but retain moisture for plant growth to continue</b>	<b>Plants flower and produce seeds, characteristic plant zones form along moisture gradient; aquatic invertebrates succumb</b>
<b>Drought</b>	<b>Summer (May – Sep)</b>	<b>Surface water gone, soils dry and cracks form in basins</b>	<b>Most plants die and deteriorate, most animals leave or succumb</b>

### **Wetting Phase**

The wetting phase begins in the fall of the year when rainfall begins to wet the vernal pools. During this period the soils begin to swell and absorb rains until water begins to accumulate at the surface. Although most of the moisture is retained in the soils during this phase, many of the dormant plants begin to sprout forming a dense cover of new seedlings.

### **Aquatic Phase**

During the aquatic phase, water begins to accumulate above the surface of the vernal pool. Plants continue to grow and the zone of wetting expands as the pool fills. With the presence of surface water, many formerly dormant aquatic invertebrates begin to develop, attracting many amphibians and aquatic birds. Many waterfowl

species migrating along the Pacific Flyway utilize this high protein food source to enhance nesting within the larger pools or to store energy before continuing their migration further north. The aquatic phase can extend into early spring each year depending upon the intensity and duration of fall and winter rains.

### **Drying Phase**

The drying phase begins after rains cease in winter and when water levels within the pools begin to decline. During this phase, vernal pools often develop characteristic rings of vegetation as different plant species migrate down the moisture gradient as water levels decrease. High water storage capacity in the soils delays the effect of complete surface water loss and provides additional time for plants to develop seeds. Many of the plants begin to form seeds as though in anticipation of the pending conditions during the warm, dry summer. Many of the invertebrates also lay eggs that will be available to populate the pool next fall or disseminate in the wind during the summer and populate other vernal pools when the rains return.

### **Drought Phase**

The drought phase begins when most of those plant species which began to germinate in the fall have died and turned brown (Zedler 1987). Soils, typically high in clay content, begin to bake in the summer sun becoming nearly as hard as concrete. Many barren areas become apparent within the pool as wetland plants die and the surface is too inhospitable for terrestrial plants to invade. The plants that occupied the pool during the aquatic phase break apart and identification becomes difficult. All invertebrates and amphibians that occupied the vernal pool when it was wet also disappear.



## **Geographic Extent within California**

California has experienced extensive wetland losses during the last century. Large areas have been converted from wetlands to agricultural production, including vineyards for grape and wine production. Extensive areas have been converted for urban development as the population of California has rapidly expanded.

Vernal pools occur primarily in two locations within California. One occurs along the coastal terraces and level topography of the lower coastal mountains and the other in the Central Valley (Holland and Jain, 1977) (Figure 1). These two areas occur within the Mediterranean Division, one of the ecoregions defined by Miles and Goudey (1997) based on a modification of ecoregions by Bailey (1994) and Bailey et al. (1994).

The Central Valley has similarly seen a dramatic decline in wetland area. Frayer et al. (1989) analyzed the status and trends of wetlands in the Central Valley during the period from 1939 to the mid-1980's. They estimated that of the 5.26 million hectares in the Central Valley, 1.62 million hectares were wetlands in the 1850's. By the mid-1980's, only about 153,300 hectares, or 9 percent remained. Almost all of this loss occurred in freshwater emergent wetlands, of which vernal pools represent one type. Between 1939 and the mid-1980's agricultural conversion accounted for approximately 95 percent of the net loss of palustrine wetlands (Frayer et al. 1989).

Due to the seasonal dynamics of vernal pools, few researchers have tried to quantify the geographic extent of these ecosystems. Holland (1978) found that vernal pools occur in two main clusters in California.

Partly because of their seasonal cycles, and because of the tremendous economic pressures to convert vernal pools to urban areas and agriculture, particularly vineyards, there has been a growing concern for the ecological benefits provided by these wetlands. Vernal pools in the Sacramento area also provide habitat to a diverse invertebrate fauna and plant community; many species of which are Federally or locally listed as threatened or endangered.

The project area for this dissertation is confined to those vernal pools within Sacramento County in the Central Valley of California. The regional subclass is the Northern claypan vernal pools found within the Hardpan Terraces subsection of the Great Valley Section ecoregions as described by Miles and Goudey (1997).

## Climate

Vernal pools undergo a dramatic change from wet to dry conditions each year as a consequence of the seasonal climatic conditions where vernal pools occur. The contrast between wet winters and dry summers occurs in response to the shift in the belt of stormy westerlies from the south in winter to the north in summer (Major 1977). A subtropical high forms over the Pacific Ocean during the summer causing subsiding air and a stable atmosphere. Skies are usually cloudless except along coastal areas. Occasionally tropical storms will develop in southern California during the summer but these storms seldom move far enough north to contribute much moisture to other areas of the state where vernal pools occur. There is no record of summer rainfall stimulating significant vegetative growth in vernal pools during the summer (Zedler 1987).

It is not until about October that precipitation is sufficient to start filling the pools, since most of the earlier precipitation was absorbed into the soils desiccated by the long, dry summers. Pools remain filled until about April or May in most years; then the summer temperatures begin to again dry the pools.

Precipitation varies widely in the state (Figure 7) but ranged from 38 to 51 cm per year during the period from 1961 to 1990. Temperatures at the Sacramento Airport indicate a similar seasonal pattern as that experienced by much of the rest of the state

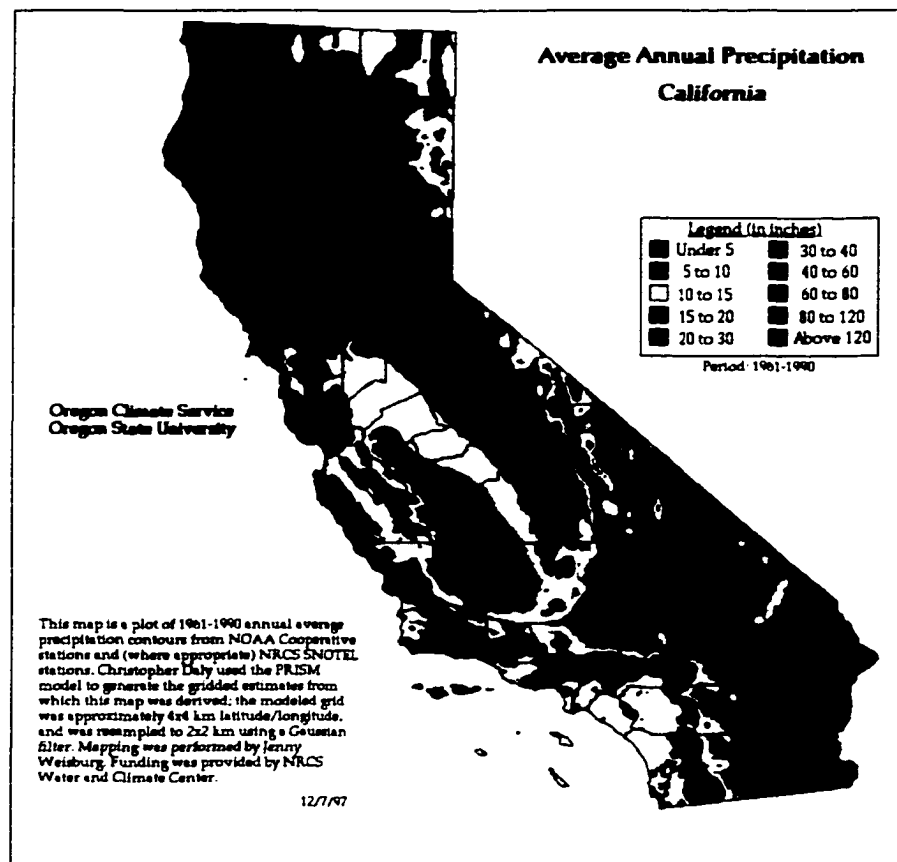


Figure 7. Distribution of average annual precipitation for California. Sacramento County is located in the light green area and receives approximately 38 cm (15 inches) to 51 cm (20 inches) per year.

with coolest temperatures in November and December and warmest temperatures in June and July (Figure 8).

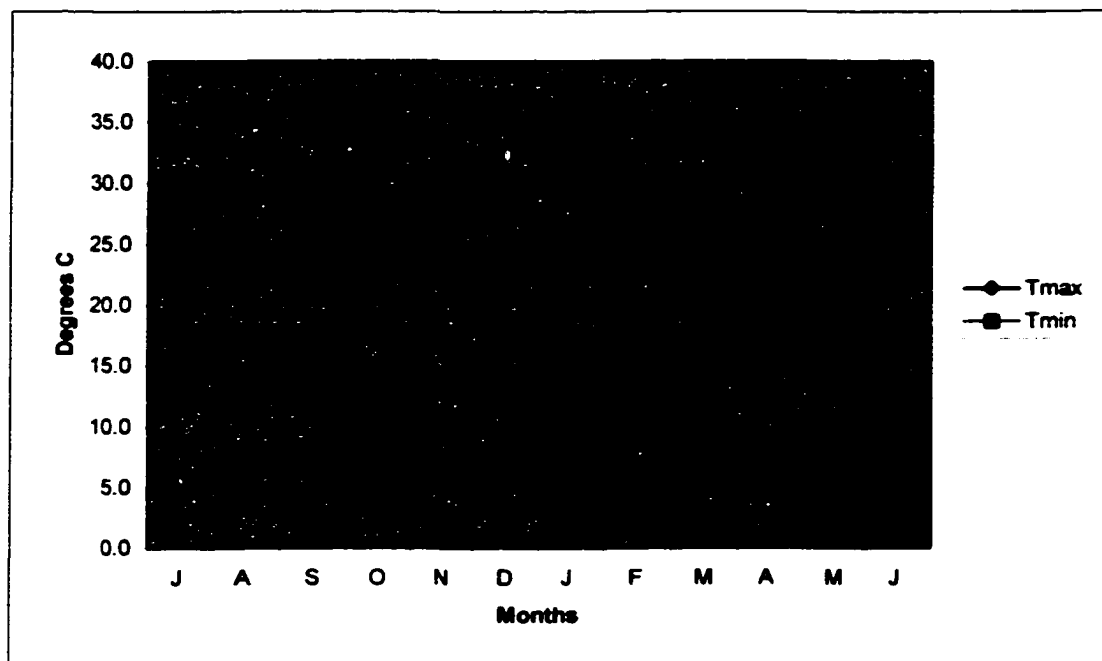


Figure 8. Climatic data for Sacramento, California, indicating monthly maximum (Tmax) and minimum (Tmin) temperatures (°C) (period of record 1944 to 1999).

### Landscape Complexes and Mounds

Vernal pools occur in a fairly distinctive landscape setting. Pools can only form in depressions underlain with a nearly impermeable layer. Three major geomorphic situations that occur in California provide these conditions; coastal terraces, broad alluvial valleys like the Sacramento Valley, and ancient basaltic lava flows (Zedler 1987).

Since vernal pools occur in shallow depressions, they are often associated with gently undulating topography. Mounds between depressions form small watersheds from which surface flows can drain into the depressions or subsurface flows can slowly seep.

This topography is represented by a combination of shallow depressions distributed among low mounds and has been referred to as “pimpled prairie or pimpled mounds” in areas of the southeast and has been observed in Arkansas by this author. The term “hogwallows” is often used in California (Nikiforoff 1941). However, a term that has been around for many years (Bretz 1913) but seems to be in more common use today is “mima mounds.” This term is derived from the Mima Prairie in Washington State (Zedler 1987). Therefore, vernal pool complexes consist of the shallow depressions called vernal pools and the mounded topography that is referred to as mima mounds.

### Hydrology and Hydrodynamics

As previously discussed under the climate section, rainfall typically begins to fill the vernal pools in late fall with pools remaining ponded until early spring. The pools are completely dry during summer before again becoming ponded the following year. Using a conventional hydrologic model with inflows and outflows, a vernal pool receives nearly all of its inflow directly from precipitation. A small amount is derived from runoff from the adjacent watershed but pools are small and so are their watersheds. Water losses are predominantly a result of evaporation and transpiration. Since vernal pools form on nearly impermeable subsoil, little water is lost directly through underlying soil. However, soils within the pool basin and in the surrounding mima mounds can absorb early season rainfall and retain that moisture until late in the spring. This is an important source of water for the plants during the period when pools are drying and contributes to the slow decline of the plant community well after the surface water is gone. Since vernal pools also seldom experience waters flowing

through the pool except during short intense rainfall events when the pools are at their maximum depths, pools are seldom subject to high water velocities. Therefore, vernal pools reflect low-energy vertical water fluctuations and little erosion due to water movement. In some very large vernal pools like one in the Jepson Prairie near Davis, California, wave energy tends to scour the shoreline, resulting in impeded plant growth immediately adjacent to the interface between water and mima mound.

## **Soils**

Soil conditions vary considerably from one location to the next within California but one common characteristic of soils associated with vernal pools is the presence of a restricting layer underlying the vernal pool. Soils occurring in vernal pool complexes are typically formed in alluvial materials and are heavily weathered with subsoils high in clay (Zedler 1987). This high clay content is instrumental in impeding vertical water movement. As one might expect in a vernal pool complex, soils also often occur as soil complexes. A soil complex is a map unit of two or more kinds of soil or miscellaneous areas occurring in such an intricate pattern or so small in area that it is not practical to map them separately (Tugel et al. 1993). The primary soil type is typically associated with the mima mounds and the inclusions are associated with the vernal pool basins.

Vernal pools sampled in the Sacramento area were primarily represented by the San Joaquin silt loam with 0-3 percent slopes and the Red Bluff-Redding complex with 0-5 percent slopes. Other map units identified at sampled areas included the San Joaquin-Galt complex with 0-3 percent slopes, Redding gravelly loam with 0-8 percent slopes, Hedge loam with 0-2 percent slopes, and the Hicksville loam with 0-2

percent slopes. A short description of each map unit is provided in Chapter 5 for each vernal pool complex sampled.

## Flora

The dramatic contrast in wetting and drying seasonal cycles leads to very unique conditions for both the flora and fauna that inhabit vernal pools. Therefore, vernal pools are widely recognized as supporting many unique plants and animals. Wetland plants, however, are afforded a longer period for reproduction because moisture is often retained within the high-clay-content soils after the surface water has disappeared. As the vernal pools dry, plants form concentric rings following the available soil moisture. Upon complete drying, the fragile annuals, which represent the dominant vegetative component of vernal pools, tend to wither and disintegrate. During these very dry conditions in the summer, other non-native plant species can invade the pools.

Zedler (1987) listed 47 vascular plant species he classified as restricted to vernal pools and an additional 81 species occurring in pools. He also listed 23 plant species that are commonly found in the vicinity of vernal pools. This diversity of plant species reflects the dynamic seasonal nature of the pools where numerous moisture regimes provide many opportunities for plants to occur. Twenty-three species were Federally listed, threatened, or endangered or were proposed as candidate species for listing pursuant to the Endangered Species Act at the time of data collection (Larry Vinzant, USCOE, Sacramento, personal communication, 1999).

Typical plant species restricted to vernal pools include *Eryngium vaseyi*, *Lasthenia glaberrima*, *Plagiobothrys stipitatus*, *Callitriche stipitatus*, *Callitriche*

*marginata*, *Crassula aquatica*, and *Isoetes howelli*. Some species common near vernal pools but that usually do not occur in the pool include *Anthemis cotula* and *Bromus diandrus*. In addition to the vascular plants, several algal species often develop in pools, forming a thin mat on the pool basin as the pools dry. Several families of algae represented in collections near Dixon, California, in the Central Valley include the following: Cyanophyceae, Chlorophyceae, Charophyceae, Euglenophyceae, Xanthophyceae, and Bacillariophyceae (Zedler 1987).

### **Invertebrate Fauna**

Vernal pools support a rich assemblage of invertebrate species including fairy shrimp and tadpole shrimp. Other aquatic invertebrates include aquatic earthworms, clam shrimp, copepods, seed shrimp, water fleas, water mites, and beetles. Most of the faunal species must complete their life cycles within approximately 60 days or less. To survive the harsh extremes of summer drought and total desiccation, vernal pool invertebrates have evolved survival mechanisms for eggs to survive. Not all eggs will hatch in one particular hatching season, thereby providing viable eggs for several hatching seasons. Three species of fairy shrimp, *Branchinecta lynchi*, *Branchinecta longiantenna*, *Branchinecta conservatio*, and one species of tadpole shrimp, *Leidurus packardii* have been listed as Federally threatened or endangered.

### **Vertebrate Fauna**

Many vertebrate species also utilize vernal pool habitats during some part of their life cycle. The western toad (*Bufo boreas*), western spadefoot toad (*Scaphiopus*



*hammondi*), Pacific tree frog (*Hyla regilla*), and occasionally the California tiger salamander (*Ambystoma californiense*) occur in vernal pools. Vernal pools typically pond long enough for these vertebrates to complete their life cycle requirements which is about two months for the western toad and Pacific tree frog and as little as a month (Stebbins 1996) for the spadefoot toad. However, the pools usually do not stay ponded long enough or deep enough to meet like cycle requirements of the California tiger salamander, which requires approximately three and one-half months.

Resident and migratory shorebirds such as avocets and mallards regularly use vernal pools during the aquatic phase. The high protein and calcium rich invertebrate diet is particularly important to shorebirds and waterfowl migrating northward for the spring nesting season. Vernal pools also provide important spring mating sites for migrating waterfowl. Occasionally, waterfowl and shorebirds will also utilize larger vernal pools for nesting sites.

### **Anthropogenic Influences**

Vernal pools have been subjected to numerous human uses. Since vernal pool complexes tend to contain many shallow depressions that retain water into the early spring, they have provided important areas for cattle grazing. Vernal pool complexes have also been subjected to land leveling to enhance dryland farming. A strong demand for California wines has also stimulated conversion of vernal pool complexes to vineyards. The burgeoning California population has also led to tremendous demands for residential development and many vernal pool complexes have been filled and converted to housing projects.

## **Description of Vernal Pool Complexes Sampled**

Seven vernal pool complexes were sampled during the course of this dissertation. Complexes were sampled at Valensin Ranch (VR), Sunrise Douglas (SD), Elliott Ranch (ER), Churchill Downs (CD), Laguna Creek (LC), Teichert Aggregates (TA), and Mountain Top (MT). At each vernal pool complex, at least one sample area was established following procedures described in Chapter 3 above. At three locations, Sunrise Douglas, Churchill Downs, and Laguna Creek, two sample areas were established. Each vernal pool complex (and, where appropriate, sample areas) is briefly described below, including the location by latitude and longitude of the approximate center of the complex or sample area. Also provided is the USGS quadrangle, approximate distance from the state capital in Sacramento, and a short description of the management history. Mr. Larry Vinzant of the U.S. Army Corps of Engineers District office in Sacramento provided much of the information for the vernal pool complex descriptions. The sample areas were positioned where the landowners would permit access and chosen to represent the general character of the vernal pools within the complex.

### **Valensin Ranch**

Valensin Ranch (VR) is located about 30.5 km east southeast of Sacramento on the Galt and Clay USGS quadrangles at approximately 38° 18' 30" latitude and 121° 16' 30" longitude (Figure 3). The entire ranch is large, encompassing approximately 1,750 hectares. There are several small roads that fragment the property with the area sampled, part of an 1,175-hectare parcel. The Nature Conservancy and several state

agencies owned the property at the time of data collection. The USDA Natural Resources Conservation Service subsequently acquitted about 75 percent of the property under the Wetlands Reserve Program. However, it had been owned by the Valensin family since the 1870s and was used primarily for cattle ranching. In the 1990s, a new town was proposed at the site but it did not materialize and the ranch was purchased by the present owners. Currently the site is being managed to restore grassland/vernal pool ecosystems including some grazing and prescribed burning. It is also used for research, particularly census studies on the flora and fauna.

One sample area was established at VR. It encompassed an area of 65,772 m<sup>2</sup> and included 51 vernal pools about equally distributed between isolated and connected pools. No constructed pools occurred in the sample area. A total of 11 vernal pools were sampled at the VR vernal pool complex.

The sample area was underlain with a San Joaquin – Galt complex on 0 to 3 percent slopes. The map unit is about 45 percent San Joaquin soil and about 40 percent Galt soil. San Joaquin soils occur in the mima mounds on slopes of 0 to 3 percent and Galt soils occur in the vernal pool basins on slopes of 0 to 2 percent. Both soils are moderately deep and well-drained and permeability is slow in the Galt soil to very slow in the San Joaquin soil. Clay content is high in both soils and both have a high shrink-swell potential. Depth to the hardpan typically ranges from 50 to 90 centimeters for these soils but ranged from 64 to 76 centimeters in the pools sampled.

Vegetative data were obtained from 281 vegetation plots in the 11 vernal pools sampled. A total of 56 plant species were observed within the vernal pools and their

immediate watershed. The ratio of native:nonnative plant species varied from 3.5 to 100 percent in the pools and 0.0 to 2.6 percent outside the pools. The disturbance quotient for the site averaged 0.92 and was considered a site near reference standard conditions with very little disturbance.

### **Sunrise Douglas**

Sunrise Douglas (SD) is located about 23 km east of Sacramento on the Buffalo Creek quadrangle at approximately 38° 32' 30" latitude and 121° 13' 30" (Figure 3). The site encompasses approximately 500 hectares and is owned by a private corporation. The land has been dryland farmed in the past, but not very intensively. Recent use has been primarily light to moderate cattle grazing, although cattle had been excluded for three consecutive years approximately two years before data collection. A Corps of Engineers Section 404 permit was issued for residential development several years ago, but the site has not been developed. Nearly 200 hectares of the site are set aside as a vernal pool preserve, but there is no active management other than for cattle grazing. This complex was one of the first areas where vernal pool construction was initiated on an area of about 1.2 hectares. The area where construction occurred was not sampled in this study.

Two sample areas were established at the Sunrise Douglas vernal pool complex. The sample area at Sunrise Douglas 1 (SD1) encompassed 61,474 m<sup>2</sup> and had 23 vernal pools. None of the vernal pools were constructed and the natural pools were about equally distributed between isolated and connected wetland types. Seven vernal pools were sampled at SD1. Sunrise Douglas 2 (SD2) encompassed 50,227 m<sup>2</sup> and

contained 17 pools; again none were constructed. Six vernal pools were sampled at SD2 and about 65 percent of the pools at the sample area were isolated.

Both sample areas at the Sunrise Douglas vernal pool complex were underlain by the Red Bluff – Redding complex with 0 to 5 percent slope. The map unit is about 45 percent Red Bluff soil and about 40 percent Redding soil. Red Bluff soils have slopes from 2 to 5 percent and occur in the mima mounds whereas Redding soils are on 0 to 3 percent slopes in the pool basins. Red Bluff soils are very deep and well-drained, but permeability is moderately slow. Redding soils are moderately deep with very slow permeability. The depth to the hardpan is 50 to 100 centimeters. Soil profiles examined at the two sample areas ranged from 33 to 71 at SD1 and 46 to 61 at SD2.

Vegetation data were obtained at 172 vegetation plots from 7 pools at SD1. A total of 43 plant species were observed at the 7 pools. Vegetation was sampled at 110 plots from 6 vernal pools at SD2 and 33 plant species were represented. The ratio of native:nonnative species ranged from 2.0 to 15.8 at SD1 and from 4.0 to 37.0 at SD2. The disturbance quotient for SD1 averaged about 0.94 at SD1 and 1.00 at SD2. Both sites represented the best examples of reference standard conditions with very little disturbance at either sample area. SD1 scored slightly less than SD2 due to increased cattle activity at a couple of the pools.

### **Elliott Ranch**

Elliott Ranch (ER) is located about 20 km south of Sacramento on the Florin quadrangle at 38° 24' 00" latitude and 121° 28' 00" (Figure 3). The Ranch encompasses approximately 690 hectares of which 240 hectares is a proposed

preservation site for vernal pools. The preserve was set aside as mitigation for development to the north of the site. Additional wetlands were constructed in the preserve. Two development corporations owned the site at the time of data collection but ownership has since changed hands, though still in private ownership. Regardless, other than the 240-hectare preservation area, the owners have a desire to convert the site to residential development.

One sample area was established at the ER site. It encompassed 43,688 m<sup>2</sup> and contained 23 vernal pools. None of the pools were constructed and none of the pools were connected. A portion of the sample area on the west end had been scraped for fill dirt during construction of Interstate 5 and represented a considerable alteration of those pools. However, the eastern end of the sample area contained several pools that had very little disturbance and represented pools in fairly good condition. Eight vernal pools were sampled at ER, with three from the relatively undisturbed east end and the remainder from the scraped west end.

The ER vernal pool complex is underlain by the San Joaquin – Galt complex on 0 to 3 percent slopes like those at Valensin Ranch. For a description of those soil characteristics, see the soil description for Valensin Ranch. The depth to the durapan at the pools examined for soils indicated a range from 81 to 91 centimeters. However, only the three pools on the eastern end of the site were examined. No pool on the western end was examined for soil characteristics.

Vegetation data were obtained from 240 plots at 8 vernal pools. A total of 45 plant species were identified in the vegetation plots. The ratio of native:nonnative

species ranged from 3.7 to 100 percent at the sampled pools but ranged from 18.0 to 100 percent at the undisturbed pools on the east end of the sample area and 3.7 to 21.7 percent in the western scraped pools. The disturbance quotient also reflected this wide disparity in disturbance with the three eastern pools averaging about 0.95 but only 0.45 for the western pools.

## **Churchill Downs**

Churchill Downs (CD) is located about 17 km southeast of Sacramento on the Elk Grove quadrangle at approximately 38° 28' 00" latitude and 121° 20' 30" longitude (Figure 3). Until the early 1990s, the complex was used for cattle grazing. However, a private development company currently owns the site. Churchill Downs encompasses approximately 240 hectares with about 55 hectares set aside as a preservation area. However, since data collection about 75 percent of the entire site has been developed for residential use. Part of the remaining area had the pools scraped for inoculum to use at another compensation mitigation site required to compensate for an area filled for residential development.

Two sample areas were established at the Churchill Downs vernal pool complex. Churchill Downs 1 (CD1) was located west of Churchill Downs 2 (CD2) and represented the vernal pool preserve described above. CD1 encompassed 33,973 m<sup>2</sup> and contained 24 vernal pools, with 7 isolated and 17 connected. No constructed pools occurred within CD1. Five pools were sampled at CD1. CD2 encompassed 31,239 m<sup>2</sup> and contained 24 pools but was a mitigation site where the area had been scraped and pools constructed. Therefore, 16 of the 30 vernal pools in the sample area were

constructed and only 3 of the natural pools were not isolated pools. Five pools were sampled at CD2 and all were constructed pools.

Both sample areas were underlain by a San Joaquin silt loam with 0 to 3 percent slope. It contained inclusions of Galt, somewhat like the conditions at Valensin Ranch and Elliott Ranch but with less Galt. This moderately deep, moderately well-drained soil occurs on low terraces. Permeability is very slow. The hardpan typically occurs about 58 cm for this soil mapping unit. The hardpan was found between 13 and 61 cm at CD1 and between 33 and 71 cm at CD2.

Vegetation data were collected from 138 plots at CD1 and 88 plots from CD2. At CD1, a total of 31 plant species were identified and 30 at CD2. The native:nonnative species ratio ranged from 9.2 to 70 at CD1 and from 6.6 to 100 percent at CD2. The disturbance quotient for CD1 averaged 0.67 and 0.70 at CD2.

### **Laguna Creek**

Laguna Creek (LC) is located about 44 km east southeast of Sacramento on the Carbondale quadrangle at approximately 38° 25' 00" latitude and 121° 02' 30" longitude (Figure 3). It consisted of about 97 hectares at the time of sampling but is being expanded at present. Portions of the site have been leveled dryland farming while other areas of the site appear to be still in a relatively natural condition. At one time the area was a proposed for an off-site mitigation area for a residential development but the landowner lost the option to use it as a mitigation site. It was subsequently sold to a private corporation that has since constructed vernal pools on the site and is managing it



as a mitigation bank. It is also managing the area for several listed species and for sale of mitigation “credits.”

Two sample areas were established at the Laguna Creek vernal pool complex. Laguna Creek 1 (LC1) encompassed 23,043 m<sup>2</sup> and contained 12 pools of which 3 were constructed pools. Four pools were sampled; two were constructed and all were isolated. Laguna Creek 2 (LC2) encompassed 51,906 m<sup>2</sup> and contained 52 vernal pools of which 19 were constructed. A total of seven natural pools were sampled in LC2.

Soils at the Laguna Creek site were represented by Redding gravelly loam with 0 to 8 percent slopes. This soil is moderately deep and well-drained and found on high terraces. The depth to the very gravelly hardpan is about 71 cm. Permeability is very slow. No soil samples were examined at LC1 but seven pools were examined at LC2. The depth to the hardpan at the pools examined ranged from 66 to 102 cm.

Vegetation data were obtained from 102 plots at 4 vernal pools at LC1. A total of 45 plant species were identified. Seven pools were sampled at LC2 with 38 species found in 110 plots. The ratio of native:nonnative species varied from 0.87 to 36.8 at LC1 and from 3.6 to 39.5 at LC2. The disturbance quotient averaged 0.51 at LC1 and 0.86 at LC2.

### **Teigert Aggregates**

Teigert Aggregates (TA) is located about 15 km southeast of Sacramento on the Carmichael quadrangle at approximately 38° 31' 30" latitude and 121° 19' 30" longitude (Figure 3). It is owned by Teigert Aggregates and encompasses about 105 hectares. The area was leveled several decades ago and remains very flat. More

recently it has been used for hay production and cattle grazing. It has also been proposed as a site for aggregate mining but that proposal has not been realized at the time of this writing.

One sample area was established at the Teigert Aggregates (TA) vernal pool complex. It encompassed 43,230 m<sup>2</sup> and included 23 vernal pools. No constructed pools were identified at TA but about 65 percent of the pools were connected by extremely shallow, winding swales. Pools at TA were extremely difficult to identify because of the level topography and lack of distinctive edge slope at the interface between the vernal pool and the non-jurisdictional area. Seven pools were sampled for vegetation.

Soils at the TA vernal pool complex consisted of Hedge loam with 0 to 2 percent slopes. This soil is moderately deep and moderately well-drained on low terraces. Permeability is moderately slow and depth to the weakly cemented durapan is typically about 96 to 112 cm. Soil profiles were examined at nine vernal pools at TA. Five of the pools were the same as for the vegetation sampling and the others did not have vegetation data. Although a characteristic soil profile for a Hedge loam soil would typically have a depth to durapan between 96 and 112 cm, data for TA indicated a range of 38 to 69 cm to the durapan, an indication of prior land leveling activity as described by local personnel.

Vegetation percent cover was described at 78 plots in 7 vernal pools. Twenty-six plant species were identified. The ratio of native:nonnative plant species varied from 0.53 to 1.2 inside the pools and was 0.37 outside. This vernal pool complex was

heavily altered due to prior land leveling and heavy grazing and the disturbance quotient was 0.37 for all pools examined.

### **Mountain Top**

Mountain Top (MT) is located about 25.5 km southeast of Sacramento on the Goose Creek and Clay Station quadrangles at approximately 38° 21' 30" latitude and 121° 07' 00" longitude (Figure 3). While a private farming company currently owns the site, the author assumes that cattle historically grazed it, although that has not been confirmed. More recently, the site was deep ripped the year prior to data collection. Deep ripping is a process typically employed to break the confining clay layer and enhance subsurface drainage of the vernal pools. Deep ripping was performed at the site in two directions to a depth of about two meters according to personal communication with several local regulators and private consultants. The land was deep ripped and leveled shortly before data collection (Figure 4 a) and was planted in vineyards within a few months after data collection (Figure 4 b).

One sample area was established at MT. It covered an area of 69,424 m<sup>2</sup> and included all 8 vernal pools that could be identified at the complex. All eight vernal pools were sampled for vegetation and soils. All pools were considered isolated and none was a constructed pool.

Soils at MT were characterized as Hicksville loam with 0 to 2 percent slopes, moderately well-drained. The site also had inclusions of Corning, a moderately-well drained soil.. This is a very deep, moderately well-drained soil often found on stream terraces. A small stream was located on the north side of the sample area. Permeability

is moderately slow. In areas associated with Corning and several other soil types, the depth to the consolidated sediments ranges from 102 to 152 cm. Due to the deep ripping, no durapan was detected at any of the eight soil profiles examined.

Plant composition and percent cover were examined at all eight vernal pools for 256 plots. A total of 25 species were identified in the pools and surrounding watersheds. The ratio of native:nonnative plant species ranged from 0.21 to 1.6, the lowest ratios identified for all the sample areas except TA, which, as previously mentioned, was also extremely altered. The disturbance quotient for MT was 0.00 indicating that it was not only significantly altered but that the vernal pools cannot be restored because the restricting layer has been destroyed.

## CHAPTER 5: RESULTS AND DISCUSSION

Seven vernal pool complexes were selected in Sacramento County, California, for data collection. The complexes represented different disturbance conditions ranging from nearly completely undisturbed like those at Sunrise Douglas to totally destroyed like those at Mountain Top. Two complexes were destroyed within a year after data collection; Mountain Top was converted to a vineyard and the two sample areas at Churchill Downs were converted to residential development. Ten sample areas encompassing a total of 473,975.1 m<sup>2</sup> were established within the 7 vernal pool complexes. A total of 265 vernal pools were surveyed within the 10 sample areas. Each pool was classified as either isolated or connected and natural or constructed. Shallow swales between connected pools were also identified. The area of shallow swales between connected pools was also calculated. A subsample of 69 vernal pools was selected and a disturbance quotient computed for each of the 69 pools in the subsample. A portion of the vernal pools in the subsample were selected to provide additional detail on the topographic characteristics of each, and to characterize the soils and vegetation. More specific results are provided below for the disturbance quotient, topographic data, and characterization of the soils and vegetation.

### Disturbance Quotient

A disturbance quotient (DQ) was computed for each of the vernal pools in the subsample within each complex using methods described in Chapter 3. Pool 18 was located outside of the sample area at Valensin Ranch so it did not have some attributes (such as percent of the sample area) associated with pools within the sample area. However, a DQ was computed for Pool 18 and it was included in the overall

disturbance quotient for that complex. Topographic information was also collected at Pool 18 so those data are incorporated in the analysis of topography. However, no vegetation or soils data were collected at that pool so it is not used in analysis of those characteristics.

The average DQ for each vernal pool complex (Table 4) ranged from 0.03 for Mountain Top to 1.0 for Sunrise Douglas. The calculated DQs were then standardized to provide a range from 0.0 to 1.0, consistent with the range for indices in the HGM Approach (Figure 9). However, this standardization resulted in only very minor deviation from the calculated values (as one might expect) since the calculated values nearly matched the range of 0.0 to 1.0. However, the distribution of the DQ was not uniform. The DQ for the vernal pool complex at Tiegert Aggregates, the next-most degraded site, averaged 0.37 (Figure 9).

This gap in the DQ from 0.0 at Mountain Top to 0.37 at Tiegert Aggregates suggests that some additional sites should have been collected to provide a more complete range of disturbances at the lower end of the DQ. The DQ did seem, however, to represent the general level of degradation at both the complex level and, to a lesser extent, at the individual vernal pool level. At the Elliott Ranch vernal pool complex, for example, individual pools were located in two distinct areas of disturbance. A series of pools on the west side of the sample area were scraped for construction materials for Interstate 5. These pools scored considerably lower than those pools on the east end of the sample area where no such disturbance occurred. There was a clear distinction between the scraped and unscraped areas because there was a sharp topographic break of approximately one meter delineating the beginning

Table 4. Disturbance quotient for each vernal pool and the average disturbance quotient for each vernal pool complex. Pools are sorted by DQ within each sample area (Continued).

VERNAL POOL COMPLEX	POOL NUMBER	DQ CALCULATED	DQ STANDARDIZED	DQ NORM AVERAGE
<b>Valensin Ranch</b>				<b>0.9</b>
	1	0.92	0.91	
	2	0.92	0.91	
	3	0.92	0.91	
	4	0.92	0.91	
	5	0.92	0.91	
	10	0.92	0.91	
	11	0.92	0.91	
	12	0.92	0.91	
	13	0.92	0.91	
	14	0.92	0.91	
	18	0.92	0.91	
<b>Sunrise Douglas 1</b>				<b>0.8</b>
	5	0.80	0.79	
	7	0.80	0.79	
	4	0.83	0.83	
	15	0.83	0.83	
	27	0.83	0.83	
	2	1.00	1.00	
	8	1.00	1.00	
<b>Sunrise Douglas 2</b>				<b>1.0</b>
	7	1.00	1.00	
	14	1.00	1.00	
	17	1.00	1.00	
	18	1.00	1.00	
	20	1.00	1.00	
	21	1.00	1.00	
<b>Elliott Ranch</b>				<b>0.5</b>
	10	0.41	0.39	
	13	0.41	0.39	
	15	0.41	0.39	
	18	0.41	0.39	
	21	0.41	0.39	
	2	0.79	0.79	
	4	0.94	0.94	
	6	0.96	0.96	

Table 4. (Concluded).

<b>Churchill Downs 1</b>				<b>0.63</b>
	9	0.6	0.60	
	11	0.6	0.62	
	7	0.6	0.62	
	10	0.6	0.65	
	6	0.6	0.66	
<b>Churchill Downs 2</b>				<b>0.56</b>
	2	0.5	0.53	
	1	0.5	0.57	
	3	0.5	0.57	
	4	0.5	0.57	
	5	0.5	0.57	
<b>Laguna Creek 1</b>				<b>0.48</b>
	2	0.4	0.38	
	11	0.4	0.43	
	12	0.4	0.43	
	3	0.7	0.69	
<b>Laguna Creek 2</b>				<b>0.79</b>
	4	0.8	0.79	
	9	0.8	0.79	
	10	0.8	0.79	
	17	0.8	0.79	
	22	0.8	0.79	
	39	0.8	0.79	
	43	0.8	0.79	
<b>Teigert Aggregates</b>				<b>0.37</b>
	8	0.3	0.37	
	1	0.3	0.37	
	2	0.3	0.37	
	3	0.3	0.37	
	4	0.3	0.37	
	5	0.3	0.37	
	6	0.3	0.37	
	7	0.3	0.37	
<b>Mountain Top</b>				<b>0.00</b>
	1	0.0	0.00	
	2	0.0	0.00	
	3	0.0	0.00	
	4	0.0	0.00	
	5	0.0	0.00	
	6	0.0	0.00	
	7	0.0	0.00	
	8	0.0	0.00	



and ending of the scraping. Pools 2, 4, and 6, at the east end of the sample area at Elliott Ranch, scored 0.79, 0.94, and 0.96, respectively. However, all the scraped pools on the west side scored 0.39.

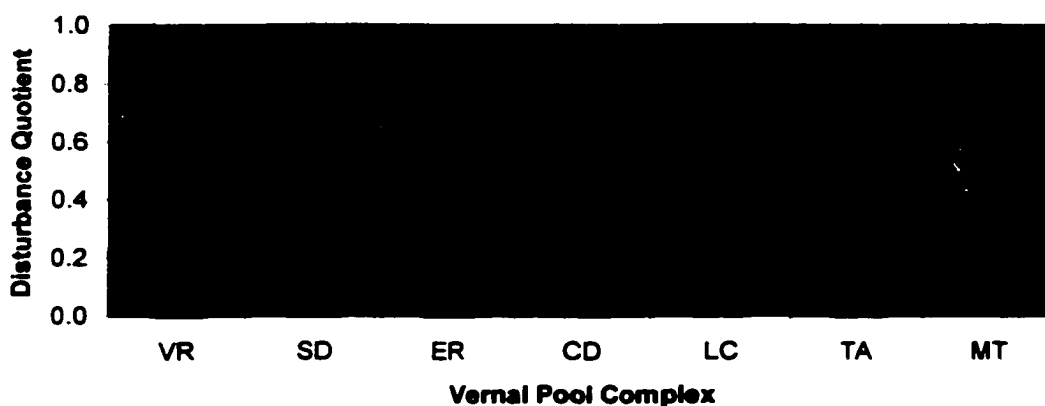


Figure 9. Relative levels of disturbance for each vernal pool sampled within each complex as calculated from the disturbance quotient. Vernal pool complexes are denoted as follows: VR = Valensin Ranch, SD = Sunrise Douglas, ER = Elliott Ranch, CD = Churchill Downs, LC = Laguna Creek, TA = Teigert Aggregates, and MT = Mountain Top.

In several situations, the DQ seemed to lack the sensitivity originally sought to discriminate different levels of disturbance at the individual pool level. It seemed to work fine at the Elliott Ranch complex, however, because there was a fairly clear and dramatic difference in the pools within the site. This lack of a marked difference at the pool level occasionally limited use of the DQ for discriminating disturbance from pool to pool within most vernal pool complexes. This lack of sensitivity could have been caused by the components used in the calculation of the DQ. Factors such as urban development and grazing were usually more influential at the complex level than at a particular pool within the complex. No individual vernal pools had

residential development within their watershed, but they certainly did within one kilometer. However, nearly all the pools within the complex were subjected equally to this level of disturbance so little discrimination from pool to pool could be achieved using this component of the DQ. Likewise, cattle grazing intensity was a very useful measure of disturbance between complexes but, typically, cattle grazed over the entire complex rather than concentrating or avoiding a particular vernal pool. Consequently, when computing this component of the DQ, it also tended to be nearly the same for all the pools within the same complex.

This shortcoming in the DQ does not diminish the role it can play in assessing wetland functions. Vernal pools are assessed at two different scales; the landscape or vernal pool complex scale and at the individual vernal pool scale. The DQ was an important component in assessing disturbance between complexes using the components applied in this study. However, for the sampling protocol and results to be applied at the individual vernal pool scale, different disturbance factors must be considered. Several of those individual factors were identified during the course of this study. For example, after all the data were collected, it became somewhat apparent that the slope of the edge of each pool differed considerably based on the observed level of degradation. Those vernal pools considered to be relatively undisturbed, usually at sites like Sunrise Douglas and Valensin Ranch, seemed to have a steeper slope at the interface between the vernal pool and the mima mound. However, pools that were scraped or subjected to land leveling during ranch or farming activities tended to have a more gradual slope at the edge. This change in slope is not surprising after seeing numerous vernal pools under different levels of

degradation, but examination of the variable was not apparent prior to data collection. If one considers the process of land leveling, the relationship of disturbance between the slope of the edge can be seen. When a pool is relatively undisturbed, the slope is fairly abrupt and the pool retains water and supports a diverse plant and animal community consistent with vernal pool ecology. However, farming or ranching undulating topography can often lead to leveling of the landscape. This process of land leveling can result in materials originally on the mima mounds being transported into the vernal pool, resulting in a smoothing of the landscape and a reduction or flattening of the slope of the edge of each altered vernal pool.

Although the DQ was not reconstructed and rescaled using this new information, the slope of the edge of each of the 69 vernal pools was calculated and used within several of the wetland function models discussed in Chapter 6. The current DQ was also used in the model for assessing landscape complexity and heterogeneity, also discussed in Chapter 6.

### Topographic Survey

Of the 266 vernal pools surveyed, 194 pools (72.4 percent) were classified as isolated and 72 (27.1 percent) were classified as connected (Table 5). Conversely, when classified as either natural or constructed, the distribution was 228 vernal pools (85.7 percent) considered natural and 38 pools (14.3 percent) constructed. The 265 vernal pools in the 10 sample areas were surveyed and the size, perimeter, percent of area, maximum depth, distance to edge of nearest pool, distance to centroid of nearest pool, and volume were computed. Several of these variables, such as the distance from edge to edge and centroid to centroid were computed because these factors are

Table 5. Distribution of vernal pools by type of pool. SA = sample area, ISO = isolated, CON = connected, NAT = natural, and CONS = constructed.

NUMBER OF POOLS						AREA OF POOLS				TOTAL
SA	ISO	CON	NAT	CONS	TOTAL	ISO	CON	NAT	CONS	AREA m <sup>2</sup>
VR	31	21	52	0	51	5299.2	3307.7	8606.9	0.0	65772.0
SD1	14	9	23	0	23	5782.0	2448.5	8230.6	0.0	61474.3
SD2	12	5	17	0	17	4305.1	846.5	5151.6	0.0	50226.9
ER	23	0	23	0	23	5360.5	0.0	5360.5	0.0	43687.5
CD1	7	17	24	0	24	710.5	3771.2	4481.6	0.0	33973.4
CD2	27	3	14	16	30	4239.4	361.2	1960.1	2640.5	31238.7
LC1	12	0	9	3	12	4953.6	0.0	2039.2	2914.3	23042.9
LC2	52	2	35	19	54	11723.2	0.0	3109.1	8614.1	51906.0
TA	8	15	23	0	23	299.2	2691.9	2991.2	0.0	43229.5
MT	8	0	8	0	8	3391.4	0.0	3391.4	0.0	69423.9
	194	72	228	38	265	46064.0	13427.0	45322.0	14169.0	473975.1
%	72.9%	27.1%	85.7%	14.3%	100.0%	9.72%	2.83%	9.56%	2.99%	
							12.55%		12.55%	

important in assessing amphibian habitat. Many amphibians migrate from one pool to the next during different life cycles so this distance was considered in the amphibian models presented in Chapter 6. A sinuosity index was also computed for each pool. The index was computed by calculating the perimeter of a circle of equal area of each pool and then calculating a ratio of the pool perimeter to the circumference of the circle. The sinuosity index was computed for possible inclusion in the invertebrate model in Chapter 6 since the interface of the pool edge to the mima mound could influence primary productivity and invertebrate habitat.

Another variable computed from the topographic survey data was the roughness of the bottom. The amount of interface between the pool water and the bottom can influence the ability of the pool to alter chemical composition in the water column. And finally, the slope of the edge of each of the 69 pools was computed because of the perceived relationship of this variable to disturbance during data collection. Pools with limited disturbances seemed to have a flat bottom and fairly

abrupt slope next to the edge of the pool. Pools with gentle slopes near the pool edge often seemed to be more severely degraded.

Distribution of pools between sample areas was not uniform (Table 5). Of the 265 vernal pools identified in all sample areas, Mountain Top had the least number of pools (3 percent) and Laguna Creek 2 had the largest number (20.4 percent). The large number at Laguna Creek 2 relates to its use as a mitigation bank, so the more revenue for the banker (i.e., more pools results in more revenue). Frequency of vernal pools did not seem related to disturbance as Valensin Ranch had about the same percent of pools as the mitigation bank at Laguna Creek 2.

The distribution of different types of pools between isolated and connected was more evenly split at Valensin Ranch than at many of the other sites, suggesting a system of interconnected pools, which is generally considered desirable for invertebrate and amphibian species. The low percentages at Mountain Top and Teigert Aggregates reflect the large amount of disturbance that has occurred at both of these sites. Mountain Top had been deep ripped prior to data collection and Teigert Aggregates had experienced many years of land leveling and grazing. Past land-leveling activities at Teigert Aggregates made it difficult to determine the edge of the pools.

Although examination of the frequency of occurrence of pools within sample areas did not reveal any obvious trend, distribution of areal extent between sample areas seemed to be more informative (Figure 10). There seemed to be more uniformity in the percent of sample areas occupied by vernal pools at all sample areas except the two most disturbed sites at Teigert and Mountain Top. The latter two had a

much smaller percent of vernal pools with neither having more than 7 percent, whereas the other sites averaged nearly 13 percent with a minimum of 10 percent. When all pools were examined relative to the total area of all sample sites (473,975.1 m<sup>2</sup>), vernal pools comprised 12.55 percent of the 473,975.1 m<sup>2</sup> sampled. This percent is higher than District personnel typically expect (8 - 10 percent) in mitigation sites. Pools averaged about 231 m<sup>2</sup>, with pools at Teigert averaging the smallest (108 m<sup>2</sup>) and Mountain Top averaging the largest (424 m<sup>2</sup>) per pool.

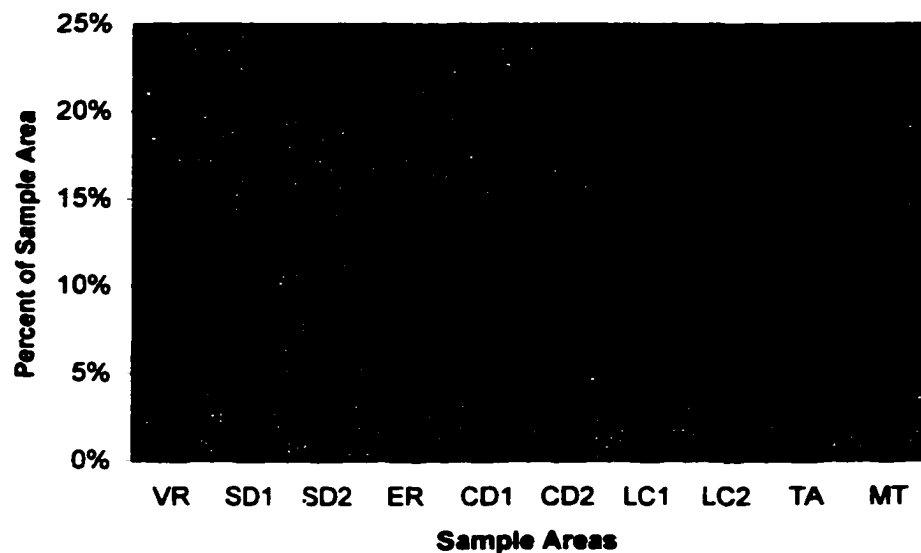


Figure 10. Percent of sample areas occupied by vernal pools. Sample areas are denoted as follows: VR = Valensin Ranch, SD1 = Sunrise Douglas 1, SD2 = Sunrise Douglas 2, ER = Elliott Ranch, CD1 = Churchill Downs 1, CD2 = Churchill Downs 2, LC1 = Laguna Creek 1, LC2 = Laguna Creek 2, TA = Teigert Aggregates, and MT = Mountain Top.

A subset of 69 vernal pools was selected for more detailed analysis from the original 266 (265 pools within the study areas and Pool 18 at Valensin Ranch located outside the study area but for which a DQ was computed). In addition to the physical characteristics assessed at the 69 pools, vegetative species composition was analyzed

at 68 pools. More detailed surveys were also performed on each of the pools to calculate the elevation and depth of each vegetative plot sampled. A total of 1,574 vegetative plots and associated elevations and depths were computed for the 68 pools.

### Soil Samples

A total of 63 vernal pools were sampled inside and on the immediate outside boundary for soil characteristics, resulting in 126 soil samples (Table 6). Profiles were described to the depth of the durapan or impermeable layer. All vernal pool complexes had an impermeable layer except Mountain Top, which had been deep ripped to destroy the durapan. The available water capacity was also computed for each soil horizon within each profile. This characteristic indicates the ability of a soil horizon to retain moisture after surface water has been depleted. The available water

Table 6. Distribution of vernal pools within vernal pool complexes and sample areas sampled for soil profiles. A profile was taken within each pool and immediately outside of each pool along the long axis.

Vernal Pool Complex	Sample Area	Number of Vernal Pools by Type of Pool				
		Isolated	Connected	Total Pools	Natural	Constructed
Valensin Ranch	VR	6	3	9	9	0
Sunrise Douglas	SD1	3	2	5	5	0
	SD2	5	0	5	5	0
Elliott Ranch	ER	7	1	8	8	0
Churchill Downs	CD1	5	2	7	7	0
	CD2	5	0	5	0	5
Laguna Creek	LC1	0	0	0	0	0
	LC2	6	1	7	7	0
Teigert Aggregates	TA	4	5	9	9	0
Mountain Top	MT	8	0	8	8	0
Totals		49	14	63	58	5

capacity is a measure of the ability of a soil to continue to provide moisture to plants after the soil surface is no longer inundated and is important in maintaining a viable vernal pool plant community. It is used in the models discussed in Chapter 6.

Another variable derived from characterization of the soil profile is the depth to the durapan and depths to each of the soil horizons. Comparison of the depth of the durapan inside the pool to the depth outside the pool for all sites, except Mountain Top, revealed that there was a significant difference ( $t=-2.7505$ ;  $P=0.007$ ) for all sites. The depth from the soil surface to the durapan was greater on the outside of the pool than on the inside. Since the downward movement of clay particles influences the position of the durapan within the soil horizon, downward movement of water through the mima mounds may transport these clay particles to greater depths due to rainfall and the lack of an impeding downward effect of saturated soils and standing water in the pools. Water in the pools has limited opportunity to move downward in the soil profile within the pool basin, except during the early wetting phase. This may result in the formation of the durapan nearer the surface than outside of the pool.

To facilitate data analysis, soil profiles were grouped into broad categories as illustrated in Table 7. The depth of each detailed horizon was determined in the field and later the depths for the broader categories were computed from the detailed data. Several variables were examined to facilitate interpretation of the soils data. Depth to the A-horizon, depth to the durapan, and available water capacity were computed for soil profiles. The difference between the available water capacity determined from field observations and the available water capacity determined from a typical soil pedon of the soil type described in the Sacramento County soil survey (Tugel et



**Table 7. List of detailed soil horizons observed at all study sites and broader soil categories for analysis.**

<b>Broad Soil Categories</b>	<b>Detailed Soil Horizon</b>	<b>Broad Soil Categories</b>	<b>Detailed Soil Horizon</b>
<b>A</b>	<b>A</b>	<b>B/BC</b>	<b>B</b>
	<b>A1</b>		<b>B1</b>
	<b>A2</b>		<b>B2</b>
	<b>A3</b>		<b>B3</b>
			<b>B4</b>
			<b>BC</b>
<b>AB,BA</b>	<b>AB</b>		
	<b>AB1</b>		
	<b>AB2</b>	<b>C</b>	<b>C</b>
	<b>BA1</b>		<b>C1</b>
	<b>BA2</b>		<b>C2</b>
			<b>C3</b>
<b>A/Bt</b>	<b>ABt</b>	<b>durapan</b>	<b>durapan</b>
	<b>ABt1</b>		<b>restrictive layer</b>
	<b>Bt</b>		
	<b>Bt1</b>		
	<b>Bt2</b>	<b>nonrestrictive layer</b>	<b>same</b>
	<b>Bt3</b>		
	<b>Bss1</b>		
<b>Ap</b>	<b>Ap</b>		
	<b>Ap/A</b>		
	<b>Ap/AB</b>		
	<b>Ap1</b>		
	<b>Ap2</b>		
	<b>Ap2/Bt1</b>		

al. 1993) was also computed. Calculation of the available water capacity was necessary since that variable was used in one of the models described in Chapter 6. Available water capacity prolongs pool drying and provides an opportunity for plants to continue growing long after the surface water has been lost. It is dependent upon soil texture, with soils high in clay content (like those in the vernal pool complexes) having a greater ability to retain moisture longer than more coarse-textured soils. Although the depth to the O-horizon is often considered in many wetland studies, it was inappropriate for use in vernal pools because the organic material tends to nearly

completely decompose each year after the pools dry. Each soil type found in the study is briefly discussed in Chapter 4 for each vernal pool complex.

### Vegetation

Percent cover of each species was determined at 68 vernal pools (Table 8) and immediately surrounding areas using visual observations from 1,574 quadrats. A total of 110 plant taxa were identified. In most instances plant taxonomy was identified to species but occasionally this level of taxonomy was not achievable due to degenerated plant conditions. In addition to plant species identified, the percent of bare ground, surface water, and algal mat coverage was estimated. Percent cover was estimated using cover classes established by Daubenmire (1959; 1968) and analyzed using the mid-point of each cover class.

Table 8. Distribution of vernal pools sampled for percent cover of vegetative species. Distribution of pools is presented by sample area and type of pool.

Sample Area	Number of Vernal Pools by Type of Pool				
	Isolated	Connected	Total Pools	Natural	Constructed
VR	6	5	11	11	0
SD1	5	2	7	7	0
SD2	4	2	6	6	0
ER	8	0	8	8	0
CD1	3	2	5	5	0
CD2	5	0	5	0	5
LC1	4	0	4	2	2
LC2	6	1	7	7	0
TA	4	3	7	7	0
MT	8	0	8	8	0
TOTALS	53	15	68	61	7

Plant composition was widely dispersed within pools but species generally were discrete between the inside and outside of each pool. Of the 110 plant species

observed, 57 species occurred within the pools and 38 of these species were found only inside the pools. Only 11 percent of the plots occurred outside of the pools, but 36 percent (n=40) of the species were observed in these plots and 20 species were only observed outside the pools. These results are consistent with those of Holland and Jain (1977) who found that vernal pools have generally resisted invasion from outside species because of the unique and challenging habitat. They also found that very few introduced species have been successful in the pool environment. In the grasslands surrounding the pools, about 38 percent of the species were introduced, whereas the pool flora contained only 5-10 percent introduced species (Holland and Jain 1977). However, there was wide variability in the average percent cover of plant species between pools.

Species were also classified as either native or non-native using the designations established by the California Native Plant Society. Variables were created from the plant composition to reflect the ratio of natives to non-natives, the percent of natives to non-natives, and the mean percent native cover within a pool. The ratio of natives to non-natives was computed simply as a ratio of the presence of the number of natives divided by the number of non-native plant species. The values for this ratio, however, became problematic in some of the analyses discussed below because the ratio could not be computed when there were no non-natives in a plot. The percent natives to non-natives was computed by determining the number of natives and non-natives in a plot and dividing that number into the number of natives. Finally, the mean percent native cover within a pool was calculated by weighting the frequency of native species in a plot by the percent cover of that species and then

dividing by the percent of the non-native species within each pool. Each of these variables was used in the analysis discussed below to assess sources of variation between sites and to determine variables for inclusion in assessment models discussed in Chapter 6.

### **Discussion**

Data collection for topography, soils, and vegetation resulted in a large number of variables (Table 9) for determining variability within and among vernal pool complexes and individual pools. Many of the variables were measured directly, such as percent cover of plant species, while others were derived from data collected in the field, such as area of the pools, which was derived from individual spot elevations during the topographic survey. Some variables were calculated from data collected. The ratio of native to non-native species was derived from field observations about individual species. Table 9 lists the variables examined and briefly describes them.

In the HGM Approach one typically precedes data collection with identification of variables that are perceived to relate to wetland functions. However, numerous other variables are also collected, which may later be determined to relate to site conditions and levels of disturbance unanticipated before data collection began. Such was the case in this study. One example is a measure of the slope of the edge of the vernal pool. Although it was anticipated that slope might be an important variable for distribution of plant species along the moisture gradient, during data collection it became apparent that the vernal pools were typically quite flat throughout most of the basin and only near the edge was there an obvious break. This break was less

**Table 9. Variables used to detect differences between complexes and pools.**

<b>VARIABLE</b>	<b>DESCRIPTION</b>
<b>PAREA</b>	Area of each pool in m <sup>2</sup>
<b>PCTAREA</b>	Percent area each pool represents of the total area of the vernal pool complex in which the pool occurs.
<b>PPERIM</b>	Perimeter of a vernal pool in meters.
<b>MAXDEP</b>	Maximum depth of a vernal pool in meters.
<b>E2E</b>	Distance in meters from the edge of a vernal pool to the edge of the nearest vernal pool.
<b>C2C</b>	Distance in meters from the centroid of a vernal pool to the centroid of the nearest vernal pool.
<b>DQNORM</b>	Standardized disturbance quotient for a pool.
<b>SINDEX</b>	Sinuosity index. Computed by determining the length of the circumference of a circle of size equal to the size of the vernal pool and dividing into the perimeter of the pool.
<b>VOL</b>	Volume of a vernal pool in m <sup>3</sup>
<b>ROUGHNES</b>	Roughness of the bottom of the pool. Computed by determining the absolute difference in elevation in each successive elevation point along each of the transects in the pool.
<b>RATIOI</b>	Ratio of the native to non-native plant species inside the pool. Computed by dividing the number of non-native species into the number of native species.
<b>AVGSLOPE</b>	Average slope of the edge of a pool. Computed by calculating the slope at a point two meters outside and two meters inside of the edge of a pool along each of the transects and averaging the two transect slopes.
<b>PCTNATI</b>	Percent of native plant species inside a pool. Calculated by dividing the number of native species by the total number of native and non-native species.
<b>MNPCTCOV</b>	Mean percent cover of native plant species inside a pool. Calculated by averaging the percent cover of all the native species in a vegetation quadrat along each transect.
<b>DEPTHHA</b>	Depth of the A-horizon. The A-horizon used here was composed of several more detailed horizons listed in Table 5.
<b>DEPTHD</b>	Depth to the durapan.

pronounced in pools that had been scraped or land-leveled, since the mima mounds were used to fill part of the pool. As a consequence of these field observations, and

because there was ample detail in the topographic survey data, this variable could be computed, although this was not anticipated at the initiation of the study. Likewise, some variables were expected to relate to the levels of disturbance observed at the sites but there was no clear correlation between those variables and disturbance after analysis.

There was also a confounding issue of scale. Several of the variables were useful at sorting out variability at the landscape or vernal pool complex level but of limited utility at the individual pool level. This was partly due to the lack of multiple observations for individual pools so one could not compute a variance for that pool variable. An example would be pool area, which represented a single observation for each pool. Other examples include several of the disturbance components (Table 2) in the disturbance quotient. Several provided an important indication of the disturbance for the complex, but were not different within many individual pools. For example, factors associated with changes in the surrounding urban environment were useful in sorting out differences, as indicated by the disturbance quotient, between complexes. However, all pools in the same complex often received very similar scores for this component of the disturbance quotient because the factor was at a landscape scale. Therefore, a two-pronged approach was taken to link landscape variables that might be useful for assessing the relative disturbance of a complex to those that indicate the relative level of disturbance of an individual pool. First, the large list of variables was narrowed to a few variables that helped discriminate between the different vernal pool complexes, which then suggested differences in disturbance. Once this subset of variables was identified to reflect disturbance, other

variables needed in the assessment models in Chapter 6 were regressed against these variables that represented levels of disturbance. Several analytical tools were used to examine the variables that most closely related to disturbance and those that also related to function.

Some of the variables listed in Table 9 were computed because of their anticipated influence on selected wetland functions. For example, the sinuosity index was computed because the effect of pond and stream edge is often an important consideration in the contribution of carbon into aquatic systems. The amount of edge also provides habitat diversity and can enhance animal communities. Roughness was examined because the amount of interface between water in the pool and the substrate can influence biogeochemical processes and contribute to assessment of nutrient cycling.

Prior to selecting variables for inclusion in subsequent analyses, it was necessary to determine if there was a significant difference between the sites themselves. A stepwise discriminant analysis was performed using all the variables listed above except the soil variables. Data for these two variables were unevenly distributed among the sites, none were available at Laguna Creek 1 and no durapan occurred at Mountain Top. This lack of data for these variables would have prevented use of data for many sites since the stepwise discriminant analysis requires complete data for all sample units (pools). Elliott Ranch was also divided into two sites because of the different set of conditions within the site as described in Chapter 4. When examining all sites and variables, only the ratios of native to non-native species inside the pool and pool perimeter were not significantly different. Comparison of all

sites indicated a highly significant difference ( $F=304.68$ ;  $P>0.0001$ ) for Wilks' lambda. Sample areas within the same vernal pool complex were also compared using 12 variables. Results indicated that Sunrise Douglas 1 and Sunrise Douglas 2 were significantly different for the Wilks' lambda ( $F=12.218$ ;  $P>0.0050$ ). A comparison of Churchill Downs 1 and Churchill Downs 2 also indicated that both sites are significantly different with respect to Wilks' lambda ( $F=18.270$ ;  $P>0.0037$ ). Laguna Creek 1 and 2 and both sites at Elliott Ranch were significantly different with respect to Wilks' lambda ( $F=130.263$  and  $P>0.0001$  for Laguna Creek and  $F=11200.00$  and  $P>0.0001$  for Elliott Ranch). With the exception of Laguna Creek, the disturbance quotient was the first variable entered in the model. At Laguna Creek, maximum depth was the first variable entered in the model and the disturbance quotient was not entered among the three variables used to discriminate between sites. Maximum depth may have been more important because one of the two sites had numerous constructed pools while the other had none, and constructed pools tended to be deeper.

The process of selecting a wide range of variables, as indicated above, reducing the variables to meaningful indicators of disturbance, and then scaling variables for inclusion in the ecological models in Chapter 6 required several steps. Initially a correlation matrix was computed to calculate the correlation between each variable, then a stepwise discriminant analysis was performed to determine if additional variables might be eliminated from further consideration and to develop a model for classifying each pool within a site. The stepwise discriminant analysis also indicated which variables had the greatest contribution in the model for classifying the



different pools into classes (sites). A discriminant analysis was then performed to assess how well the model predicted which vernal pool complex a pool would be assigned relative to the complex in which the pool actually occurred. Each of the above analyses was computed for the entire data set and for the calibration and test data sets to compare results and assess the comparability of the data sets. Finally, a blocked ANOVA was performed on the variables in the discriminant model to determine if the variables for all the pools, the pools in the calibration data set and the pools in the test data set were significantly different. Each of these analytical steps is discussed below.

### **Computation of the Correlation Matrix**

It was anticipated that certain variables would be closely correlated, such as pool area and pool perimeter, but it was desirable to see if there was a significant difference between certain variables. A correlation analysis was performed for all variables and for all sites, all sites within the calibration data set, and all sites within the test data set. In addition to the 10 sample sites originally analyzed, Elliott Ranch was divided into two sites to represent the dramatic differences within the sample area to refine data analysis. Consequently, Site 4 represents those pools at Elliott Ranch that were located on the undisturbed eastern portion of the ranch as previously discussed in Chapter 4. Site 11 represents those pools located in the scraped portion of Elliott Ranch on the western end of the site. Pearson correlation coefficients are provided in the first row of each variable and indicate the strength of the relationship, with 1.000 representing a perfect correlation. The probability that the level of correlation is due to chance is presented in the second row and the number of

observations or pools is presented in the third row. Once a correlation was identified between one or more variables, the variable that could most easily be measured in the field was given priority in inclusion for later analysis. Not all variables that were significantly correlated were deleted from the stepwise discriminant analysis computed after the correlation analysis was performed.

## **All Pools**

The number of observations is 69 for most correlation coefficients (Table 10), since Pool 18 at Valensin Ranch was also included in the analysis, although it was located immediately outside of the sample area. However, it was not included in the percent area since its position outside the sample area also meant that no percent of the sample area was computed for that pool. The number of observations also varied with the soil parameters because soils were collected at all pools where vegetation parameters were sampled. No durapan was identified at Mountain Top since the site was deep ripped. Therefore, there are eight fewer observations for those variables, since eight pools were located at Mountain Top.

After examining the correlation coefficients and probabilities, percent area and pool perimeter were dropped from subsequent analyses because these variables were not significantly different from pool area and area could more likely be easily measured or estimated quickly by field personnel. Centroid to centroid was also dropped but edge to edge was retained. This variable was originally included because amphibians that inhabit vernal pool complexes often must move from one pool to the next as pools dry. The availability of pools of differing depths and in close proximity would enhance amphibian survival. Sinuosity index and volume were also dropped,

Table 10. Correlation matrix for all variables and all vernal pools (N=69).

	PAREA	PCTAREA	PPERIM	MAXDEP	EZE	C2C	DONORM	SINDEX	VOL	ROUGHNES	RATIO	AVGSLOPE	PCTNATI	MINPCTCOV	DEPTH	DEPTHD
PAREA	1.000 0.000 69.000															
PCTAREA	0.841 0.000 64.000	1.000 0.000 64.000														
PPERIM	0.978 0.000 69.000	0.879 0.000 69.000	1.000 0.000 69.000													
MAXDEP	0.458 0.000 69.000	0.608 0.000 69.000	0.414 0.000 69.000	1.000 0.000 69.000												
EZE	0.148 0.222 69.000	0.035 0.745 69.000	0.138 0.348 69.000	-0.063 0.498 69.000	1.000 0.000 69.000											
C2C	0.508 0.000 69.000	0.394 0.000 69.000	0.498 0.000 69.000	0.098 0.433 69.000	0.794 0.000 69.000	1.000 0.000 69.000										
DONORM	0.175 0.150 69.000	0.105 0.358 69.000	0.207 0.044 69.000	0.001 0.942 69.000	-0.440 0.000 69.000	-0.385 0.000 69.000	1.000 0.000 69.000									
SINDEX	-0.455 0.000 69.000	-0.483 0.000 69.000	-0.482 0.000 69.000	-0.235 0.000 69.000	0.023 0.000 69.000	-0.313 0.000 69.000	-0.152 0.000 69.000	1.000 0.000 69.000								
VOL	0.553 0.000 69.000	0.545 0.000 69.000	0.534 0.000 69.000	0.387 0.000 69.000	0.180 0.119 69.000	0.408 0.000 69.000	-0.185 0.179 69.000	-0.261 0.030 69.000	1.000 0.000 69.000							
ROUGHNES	0.072 0.556 69.000	0.117 0.341 69.000	0.045 0.715 69.000	0.346 0.004 69.000	0.079 0.517 69.000	0.038 0.770 69.000	-0.030 0.809 69.000	-0.148 0.182 69.000	0.163 0.000 69.000	1.000 0.000 69.000						
RATIO	0.102 0.414 66.000	0.179 0.154 65.000	0.129 0.301 65.000	0.112 0.368 65.000	-0.282 0.034 65.000	-0.158 0.202 65.000	0.308 0.012 65.000	-0.219 0.077 65.000	-0.060 0.633 65.000	-0.053 0.674 65.000	1.000 0.000 65.000					
AVGSLOPE	0.444 0.000 69.000	0.485 0.000 69.000	0.487 0.000 69.000	0.437 0.000 69.000	-0.178 0.143 69.000	0.035 0.971 69.000	0.317 0.004 69.000	-0.318 0.004 69.000	0.179 0.141 69.000	0.537 0.000 69.000	0.232 0.000 69.000	1.000 0.000 69.000				
PCTNATI	0.222 0.087 69.000	0.276 0.073 69.000	0.245 0.043 69.000	0.315 0.008 69.000	-0.498 0.000 69.000	-0.306 0.002 69.000	0.730 0.000 69.000	-0.288 0.077 69.000	-0.099 0.418 69.000	0.048 0.452 69.000	0.827 0.000 69.000	0.455 0.000 69.000	1.000 0.000 69.000			
MINPCTCOV	-0.019 0.000 69.000	-0.047 0.040 69.000	0.040 0.019 69.000	-0.048 0.075 69.000	-0.105 0.391 69.000	-0.105 0.391 69.000	0.378 0.002 69.000	-0.104 0.353 69.000	-0.232 0.055 69.000	-0.168 0.554 69.000	0.487 0.000 69.000	0.073 0.592 69.000	0.592 0.000 69.000	1.000 0.000 69.000		
DEPTH	0.008 0.841 52.000	0.002 0.848 52.000	0.031 0.842 52.000	0.031 0.826 52.000	0.171 0.254 52.000	0.092 0.515 52.000	0.049 0.712 52.000	-0.075 0.565 52.000	0.048 0.738 52.000	0.108 0.454 52.000	-0.214 0.140 52.000	-0.090 0.531 52.000	-0.134 0.342 52.000	-0.160 0.248 52.000	1.000 0.000 52.000	
DEPTHD	0.082 0.688 44.000	0.040 0.795 44.000	0.005 0.972 44.000	0.060 0.898 44.000	0.087 0.573 44.000	0.087 0.573 44.000	0.502 0.001 44.000	0.047 0.783 44.000	0.185 0.228 44.000	-0.099 0.383 44.000	0.019 0.408 44.000	-0.141 0.363 44.000	0.178 0.249 44.000	-0.085 0.878 44.000	1.000 0.000 44.000	

since both highly significantly correlated with pool area and both would be difficult and somewhat time-consuming to compute in the field. The ratio of natives to non-natives inside the pool was dropped because it could not be computed in the absence of non-natives (division of zero would become undefined). Instead, the variable for percent natives to non-natives was retained. Depth to the A-horizon was significantly correlated with the disturbance quotient and was also dropped, as was the depth to the durapan because of missing data in certain pools with otherwise complete information. The stepwise discriminant analysis requires data for all variables or it deletes the entire sample unit. After examining the correlation matrix and interjecting some other considerations, 8 of the 16 variables were excluded from the stepwise discriminant analysis for all pools.

### **Pools in the Calibration Data Set**

The calibration data set included 49 vernal pools. As indicated above for the entire data set, the number varied with the variable measured, since pools sampled for soil characteristics were not always the same as those sampled for vegetation. The correlation matrix for the calibration data set is provided in Table 11. Variables retained by the stepwise discriminant analysis included pool area, maximum depth, disturbance quotient, roughness, average edge slope, percent natives inside the pool, and mean percent cover of native species.

### **Pools in the Test Data Set**

The test data set included 20 pools. Data from all 20 pools were included in the correlation analysis except for soil variables as discussed previously. Results of the correlation analysis are presented in Table 12. The same variables used in the

Table 11. Correlation matrix for all variables and all vernal pools in the calibration data set (N=49).

	PAREA	PCTAREA	PPERIM	MAXDEP	E2E	C2C	DGNORM	SINDEX	VOL	ROUGHNES	RATIO	AVGSLOPE	PCTNATI	MNPCTCOV	DEPTH	DEPTHD
PAREA	1.000 0.000 49															
PCTAREA	0.850 0.000 48	1.000 0.000 48														
PPERIM	0.980 0.000 49	0.813 0.000 48	1.000 0.000 49													
MAXDEP	0.400 0.004 49	0.600 0.000 48	0.382 0.007 49	1.000 0.000 49												
E2E	0.277 0.054 49	0.185 0.207 48	0.248 0.088 49	-0.068 0.853 49	1.000 0.000 49											
C2C	0.568 0.000 49	0.484 0.001 48	0.544 0.000 49	0.108 0.458 49	0.830 0.000 49	1.000 0.000 49										
DGNORM	0.199 0.170 49	0.114 0.439 48	0.229 0.113 49	0.027 0.853 49	-0.598 0.005 49	-0.542 0.016 49	1.000 0.000 49									
SINDEX	-0.480 0.001 49	-0.488 0.000 48	-0.482 0.001 49	-0.218 0.133 49	0.010 0.944 49	-0.327 0.022 49	-0.193 0.183 49	1.000 0.000 49								
VOL	0.457 0.001 49	0.488 0.001 48	0.483 0.001 49	0.280 0.071 49	0.284 0.048 49	0.450 0.001 49	-0.283 0.088 49	-0.283 0.079 49	1.000 0.000 49							
ROUGHNES	0.097 0.507 49	0.174 0.237 48	0.092 0.332 49	0.291 0.043 49	-0.127 0.388 49	-0.028 0.851 49	-0.005 0.979 49	-0.187 0.252 49	0.213 0.141 49	1.000 0.000 49						
RATIO	0.181 0.274 48	0.244 0.098 47	0.185 0.209 48	0.200 0.172 48	-0.250 0.088 48	-0.111 0.451 48	0.438 0.002 48	-0.280 0.054 48	-0.071 0.834 48	0.012 0.834 48	1.000 0.000 48					
AVGSLOPE	0.528 0.000 49	0.628 0.000 48	0.555 0.000 49	0.485 0.001 49	-0.228 0.119 49	0.050 0.733 49	0.283 0.049 49	-0.410 0.003 49	0.172 0.238 49	0.551 0.000 49	0.283 0.051 49	1.000 0.000 49				
PCTNATI	0.202 0.185 49	0.282 0.072 48	0.225 0.121 49	0.357 0.012 49	-0.475 0.001 49	-0.382 0.011 49	0.757 0.000 49	-0.298 0.039 49	-0.209 0.149 49	0.098 0.498 49	0.837 0.000 48	0.438 0.002 48	1.000 0.000 48			
MNPCTCOV	0.068 0.653 49	0.028 0.859 48	0.098 0.514 49	0.182 0.210 49	0.008 0.927 49	-0.040 0.784 49	0.392 0.005 49	-0.120 0.411 49	-0.217 0.134 49	-0.190 0.191 49	0.307 0.034 48	0.038 0.798 48	0.582 0.000 48	1.000 0.000 48		
DEPTH	-0.040 0.818 36	0.033 0.847 36	0.002 0.992 36	0.098 0.577 36	0.226 0.188 36	0.080 0.641 36	0.104 0.548 36	0.038 0.833 36	0.097 0.575 36	0.162 0.344 36	-0.149 0.393 35	0.011 0.948 36	-0.083 0.713 36	-0.089 0.889 36	1.000 0.000 36	
DEPTHD	0.019 0.921 30	0.028 0.891 30	-0.027 0.889 30	-0.110 0.582 30	0.027 0.887 30	0.117 0.539 30	0.582 0.001 30	0.028 0.893 30	0.138 0.473 30	-0.264 0.115 30	0.278 0.148 29	-0.243 0.198 30	0.178 0.353 30	0.014 0.943 30	-0.081 0.889 30	1.000 0.000 30

Table 12. Correlation matrix for all variables and all vernal pools in the test data set (N=20).

	PAREA	PCTAREA	PPERIM	MAXDEP	EZE	C2C	DONORM	SINDEX	VOL	ROUGHNES	RATIO	AVGSLOPE	PCTNATI	MNPCTCOV	DEPTH	DEPTHD
PAREA	1.000 0.000 20															
PCTAREA	0.981 0.000 20	1.000 0.000 20														
PPERIM	0.980 0.000 20	0.987 0.000 20	1.000 0.000 20													
MAXDEP	0.617 0.004 20	0.629 0.003 20	0.552 0.012 20	1.000 0.000 20												
EZE	-0.244 0.301 20	-0.270 0.249 20	-0.300 0.199 20	-0.123 0.606 20	1.000 0.000 20											
C2C	0.273 0.243 20	0.240 0.308 20	0.247 0.294 20	0.074 0.758 20	0.695 0.001 20	1.000 0.000 20										
DONORM	0.107 0.653 20	0.084 0.725 20	0.137 0.564 20	-0.082 0.795 20	-0.558 0.011 20	-0.487 0.030 20	1.000 0.000 20									
SINDEX	-0.596 0.005 20	-0.555 0.011 20	-0.642 0.062 20	-0.396 0.081 20	0.048 0.842 20	-0.465 0.039 20	0.053 0.825 20	1.000 0.000 20								
VOL	0.641 0.000 20	0.620 0.000 20	0.642 0.000 20	0.730 0.000 20	-0.228 0.334 20	0.151 0.524 20	0.102 0.669 20	-0.442 0.051 20	1.000 0.000 20							
ROUGHNES	0.040 0.867 20	0.032 0.895 20	-0.036 0.879 20	0.443 0.050 20	0.502 0.024 20	0.283 0.228 20	-0.084 0.725 20	-0.042 0.861 20	0.090 0.705 20	1.000 0.000 20						
RATIO	0.019 0.942 18	0.100 0.892 18	0.080 0.751 18	-0.024 0.923 18	-0.290 0.243 18	-0.275 0.270 18	0.095 0.707 18	-0.020 0.839 18	0.105 0.678 18	-0.188 0.502 18	1.000 0.000 18					
AVGSLOPE	0.153 0.520 20	0.190 0.423 20	0.078 0.749 20	0.342 0.140 20	-0.033 0.890 20	-0.090 0.736 20	0.440 0.052 20	0.142 0.549 20	0.199 0.401 20	0.568 0.008 20	0.217 0.388 18	1.000 0.000 20				
PCTNATI	0.278 0.238 20	0.302 0.198 20	0.332 0.153 20	0.227 0.338 20	-0.555 0.011 20	-0.425 0.062 20	0.668 0.001 20	-0.208 0.383 20	0.260 0.269 20	0.082 0.795 20	0.654 0.003 18	0.527 0.017 20	1.000 0.000 20			
MNPCTCOV	-0.220 0.352 20	-0.183 0.439 20	-0.108 0.650 20	-0.311 0.182 20	-0.305 0.192 20	-0.304 0.193 20	0.343 0.139 20	0.005 0.885 20	-0.292 0.212 20	-0.170 0.472 20	0.707 0.001 18	0.191 0.419 20	0.653 0.002 20	1.000 0.000 20		
DEPTH	0.059 0.830 18	-0.058 0.831 18	0.046 0.886 18	-0.081 0.785 18	0.089 0.743 18	0.173 0.521 18	-0.072 0.792 18	-0.424 0.102 18	-0.081 0.825 18	0.005 0.988 18	-0.387 0.197 14	-0.264 0.270 18	-0.295 0.268 18	-0.327 0.218 18	1.000 0.000 18	
DEPTHD	0.182 0.579 14	0.097 0.742 14	0.089 0.762 14	0.219 0.452 14	0.213 0.468 14	0.014 0.982 14	0.347 0.225 14	0.070 0.811 14	0.325 0.257 14	0.208 0.479 14	-0.325 0.303 12	0.140 0.634 14	0.022 0.841 14	-0.234 0.421 14	0.171 0.560 14	1.000 0.000 14

calibration data set were included in the test data set for the stepwise discriminant analysis.

### Stepwise Discriminant Analysis

#### All Pools

Eight variables were included in the calculations and only one, edge to edge, was excluded from the model. Results are presented in Table 13 below. The average canonical correlation suggests that about 37 percent of the variability of the distribution of the sites can be captured in the 7-variable model, with the first 3 variables capturing about 24.4 percent of the variability. This suggests that other factors not measured also have a considerable influence on the distribution of vernal pools.

Table 13. Results of the stepwise discriminant analysis for all pools and selected variables determined from analysis of the correlation matrix.

Step	Variable Entered	Number In	Partial R <sup>2</sup>	F Statistic	Prob >F	Avg. Squared Canonical Correlation
1	DQ	1	0.9806	292.917	0.0001	0.09805856
2	Maxdepth	2	0.8346	28.761	0.0001	0.18124159
3	%Native	3	0.6380	9.871	0.0001	0.24376202
4	Pool Area	4	0.6193	8.948	0.0001	0.26792527
5	Roughness	5	0.6086	8.396	0.0001	0.31518673
6	Avgslope	6	0.4200	3.838	0.0006	0.34931218
7	Mn%cov	7	0.3865	3.276	0.0024	0.37137766

#### Pools in the Calibration Data Set

Results for all pools indicated that only one variable, edge to edge, should be excluded from the model so the same seven variables identified for all pools were used to run the discriminant analysis for the calibration data set. Therefore, no stepwise discriminant analysis was performed on the test data set.

## **Pools in the Test Data Set**

The same seven variables identified for all pools were used to run the discriminant analysis for the calibration data set. No stepwise discriminant analysis was performed on the test data set.

### **Discriminant Analysis**

A discriminant analysis was performed using the seven model variables identified in the steps above. The model predicts the class (sample area) to which a set of model conditions should be assigned and then compares that prediction to the actual class to which the site belongs.

#### **All Pools**

Results of the discriminant analysis are presented in Table 14 below. The discriminant model predicted all pools correctly for Valensin Ranch (12 pools), Sunrise Douglas 2 (6), Elliott Ranch eastern end (3 pools identified as sample area 4), Churchill Downs 1 (5), Laguna Creek 2 (7), Teigert Aggregates (7), Mountain Top (8), and Elliott Ranch on the western end (5 pools identified as sample area 11). In addition, four of the seven pools at Sunrise Douglas 1 were correctly assigned and two of the three others were assigned to Sunrise Douglas 2, in the same vernal pool complex. Four of the five pools at Churchill Downs 2 were also correctly assigned and three of the four at Laguna Creek 1 were correctly assigned. Therefore, 64 of the 69 pools (92.8 percent) were correctly assigned with the model variables and 3 of the 5 pools that were assigned to the wrong site were within the correct vernal pool complex.



Table 14. Results of the discriminant analysis for all 69 vernal pools. Predicted site assignments are provided across the top and actual sample area locations of pools are located to the left. Site 1 = VR, Site 2 = SD1, Site 3 = SD2, Site 4 = ER unscraped east end, Site 5 = CD1, Site 6 = CD2, Site 7 = LC1, Site 8 = LC2, Site 9 = TA, Site 10 = MT, and Site 11 = ER scraped west end.

From Sample Area	Number of Observations and Percent Classified into Sample Area										All Pools (N=69)	
	1	2	3	4	5	6	7	8	9	10	11	Total
1	12	0	0	0	0	0	0	0	0	0	0	12
	100	0	0	0	0	0	0	0	0	0	0	100
2	0	4	2	0	0	0	0	1	0	0	0	7
	0	57.14	28.57	0	0	0	0	14.29	0	0	0	100
3	0	0	6	0	0	0	0	0	0	0	0	6
	0	0	100	0	0	0	0	0	0	0	0	100
4	0	0	0	3	0	0	0	0	0	0	0	3
	0	0	0	100	0	0	0	0	0	0	0	100
5	0	0	0	0	5	0	0	0	0	0	0	5
	0	0	0	0	100	0	0	0	0	0	0	100
6	0	0	0	0	1	4	0	0	0	0	0	5
	0	0	0	0	20	80	0	0	0	0	0	100
7	0	0	0	0	0	0	3	0	0	0	1	4
	0	0	0	0	0	0	75	0	0	0	25	100
8	0	0	0	0	0	0	0	7	0	0	0	7
	0	0	0	0	0	0	0	100	0	0	0	100
9	0	0	0	0	0	0	0	0	7	0	0	7
	0	0	0	0	0	0	0	0	100	0	0	100
10	0	0	0	0	0	0	0	0	0	8	0	8
	0	0	0	0	0	0	0	0	0	100	0	100
11	0	0	0	0	0	0	0	0	0	0	5	5
	0	0	0	0	0	0	0	0	0	0	100	100
Total	12	4	8	3	6	4	3	8	7	8	6	69
Percent	17.4	5.8	11.6	4.4	8.7	5.8	4.4	11.6	10.1	11.6	8.7	100

In addition to the tabular display of the data in Table 14, a canonical discriminant analysis was computed. Canonical functions were computed for each of the seven variables in the model but the first two conical functions accounted for 94.1

percent of the model variance. The two canonical functions are presented in Figure 11. Canonical function 1 on the x-axis is in response to the disturbance quotient and the percent native species inside the pool. The maximum depth of each pool drives canonical function 2. Pools are portrayed in canonical space and seem reasonably distributed by vernal pool complex. The only anomaly in the placement of the pools occurs for Elliott Ranch pools on the western end of the site. These pools are placed with deeper pools, which one might not expect given their location in the scraped area of the site. However, examination of the data for pool depth shows that these pools were deeper than most of those located in that portion of the site. It seems that although the pools were intended to represent the shallow nature of the scraped pools, the random selection process resulted in selecting pools which turned out to be deeper than most of the other pools. All other attributes (e.g., disturbance condition and depth to the durapan), however, were consistent with most of the other pools in the scraped area.

### **Pools in the Calibration Data Set**

Results of the discriminant analysis are presented in Table 15 below. Of the 49 vernal pools in the calibration data set, 47 or 95.9 percent were correctly assigned to the correct sample area. One site at Sunrise Douglas 1 was assigned to Valensin Ranch and one site at Laguna Creek 1 was assigned to the pools on the western end of Elliott Ranch. Computing canonical functions for the calibration data set showed that two of the functions represented 95.8 percent of the variance and the same three variables comprised the two canonical functions. Pools are plotted in canonical space and presented in Figure 12.

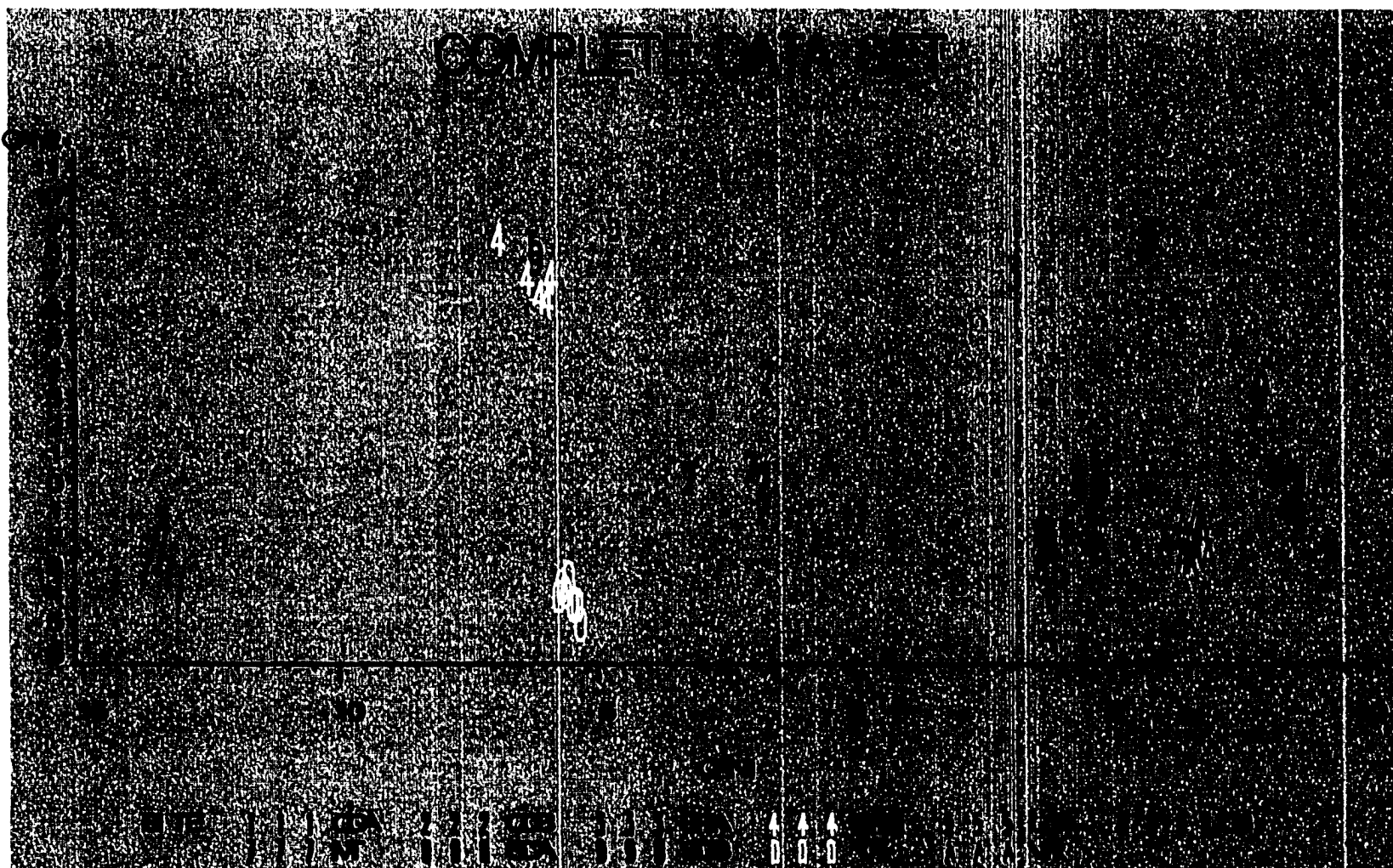


Figure 11. Scatterplot of canonical functions for all 69 vernal pools sampled. Canonical function 1 represents the disturbance quotient and percent native species in the pool. Canonical function 2 represents maximum depth of each pool.

Table 15. Results of the discriminant analysis for 49 vernal pools in the calibration data set. Predicted site assignments are provided across the top and actual sample area locations of pools are located to the left. Site 1 = VR, Site 2 = SD1, Site 3 = SD2, Site 4 = ER unscrapped east end, Site 5 = CD1, Site 6 = CD2, Site 7 = LC1, Site 8 = LC2, Site 9 = TA, Site 10 = MT, and Site 11 = ER scraped west end.

Number of Observations and Percent Classified into Sample Area									Calibration Pools (N=49)			
From Sample Area	1	2	3	4	5	6	7	8	9	10	11	Total
1	9.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9
	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
2	1.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5
	20.0	80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
3	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4
	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
4	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2
	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
5	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	3
	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	100
6	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	3
	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	100
7	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	1.0	3
	0.0	0.0	0.0	0.0	0.0	0.0	66.7	0.0	0.0	0.0	33.3	100
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	5
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	5
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	100
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0	6
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	100
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100
Total	10.0	4.0	4.0	2.0	3.0	3.0	2.0	5.0	5.0	6.0	5.0	49
Percent	20.4	8.2	8.2	4.1	6.1	6.1	4.1	10.2	10.2	12.2	10.2	100

### Pools in the Test Data Set

Results of the discriminant analysis are presented in Table 16 below. Of the 20 vernal pools in the calibration data set, 18 or 90.0 percent were correctly assigned to the correct sample area. One site at Sunrise Douglas 1 was assigned to Valensin Ranch and one site at Churchill Downs 2 was assigned to the pools on the western end

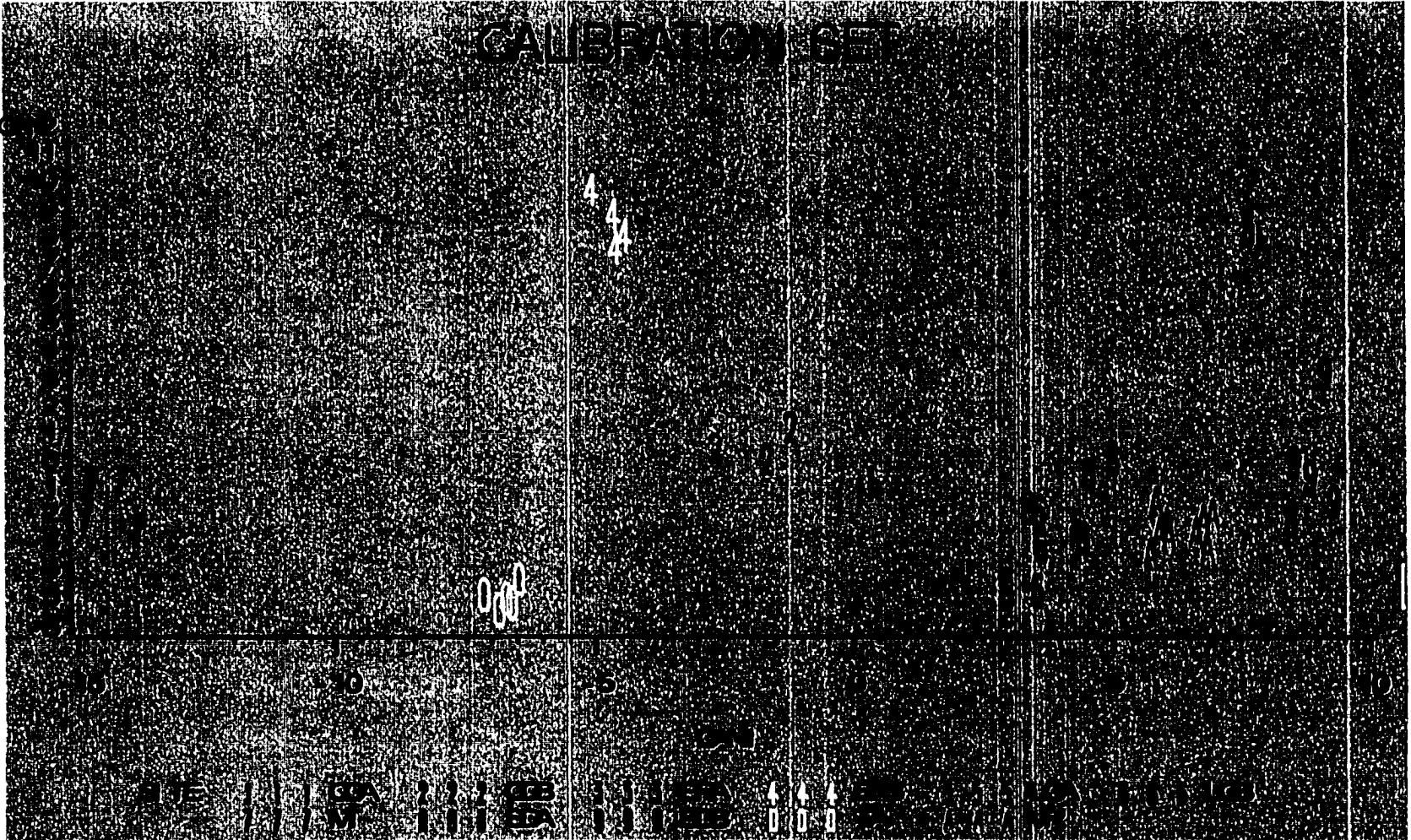


Figure 12. Scatterplot of canonical functions for all 49 vernal pools sampled in the calibration data set. Canonical function 1 represents the disturbance quotient and percent native species in the pool. Canonical function 2 represents maximum depth of each pool.

**Table 16. Results of the discriminant analysis for 20 vernal pools in the test data set. Predicted site assignments are provided across the top and actual sample area locations of pools are located to the left. Site 1 = VR, Site 2 = SD1, Site 3 = SD2, Site 4 = ER unscrapped east end, Site 5 = CD1, Site 6 = CD2, Site 7 = LC1, Site 8 = LC2, Site 9 = TA, Site 10 = MT, and Site 11 = ER scraped west end.**

Number of Observations and Percent Classified into Sample Areas										Test Pools (N=20)		
From Sample Areas	1	2	3	4	5	6	7	8	9	10	11	Total
1	3	0	0	0	0	0	0	0	0	0	0	3
	100	0	0	0	0	0	0	0	0	0	0	100
2	1	1	0	0	0	0	0	0	0	0	0	2
	50	50	0	0	0	0	0	0	0	0	0	100
3	0	0	2	0	0	0	0	0	0	0	0	2
	0	0	100	0	0	0	0	0	0	0	0	100
4	0	0	0	1	0	0	0	0	0	0	0	1
	0	0	0	100	0	0	0	0	0	0	0	100
5	0	0	0	0	2	0	0	0	0	0	0	2
	0	0	0	0	100	0	0	0	0	0	0	100
6	0	0	0	0	0	1	0	0	0	0	1	2
	0	0	0	0	0	50	0	0	0	0	50	100
7	0	0	0	0	0	0	1	0	0	0	0	1
	0	0	0	0	0	0	100	0	0	0	0	100
8	0	0	0	0	0	0	0	2	0	0	0	2
	0	0	0	0	0	0	0	100	0	0	0	100
9	0	0	0	0	0	0	0	0	2	0	0	2
	0	0	0	0	0	0	0	0	100	0	0	100
10	0	0	0	0	0	0	0	0	0	2	0	2
	0	0	0	0	0	0	0	0	0	100	0	100
11	0	0	0	0	0	0	0	0	0	0	1	1
	0	0	0	0	0	0	0	0	0	0	100	100
Total	4	1	2	1	2	1	1	2	2	2	2	20
Percent	20	5	10	5	10	5	5	10	10	10	10	100

of Elliott Ranch. Computing the canonical functions for the calibration data set showed that the same two canonical functions were driven by the same three variables as in the complete data set and the calibration data set. Pools are plotted in canonical space and presented in Figure 13.



Figure 13. Scatterplot of canonical functions for all 20 vernal pools sampled in the test data set. Canonical function 1 represents the disturbance quotient and percent native species in the pool. Canonical function 2 represents maximum depth of each pool.

## **Comparison of Calibration and Test Data Sets** **Using a Blocked AVOVA**

As a final evaluation of the similarity of the calibration and test data sets, a blocked analysis of variance was computed for all the variables in the two data sets. Data from all 69 pools were analyzed (49 pools in the calibration data set and 20 pools in the test data set). The following variables were examined: disturbance quotient, pool area, maximum depth, average edge slope, percent native plants inside the pool, mean percent cover of the native plants inside the pool, ratio of native to non-native plants inside the pool, roughness, sinuosity index, centroid to centroid, edge to edge, volume, pool perimeter, depth to the durapan, depth to the A-horizon, and percent sample area occupied by each pool. The data were blocked on the 11 sample areas. In no instance was there a significant difference between either data set for any of the variables.



## **CHAPTER 6: WETLAND FUNCTIONS AND ASSESSMENT MODELS**

This chapter provides the list of functions, and the variables and assessment models (aggregation of variables) associated with each function. The following five functions performed by hard claypan vernal pools in the Central Valley of California were selected for assessment.

- a. **Surface Water Storage in Pool Basin**
- b. **Subsurface Water Exchange**
- c. **Maintain Characteristic Habitat for Vernal Pool Vegetation**
- d. **Maintain Characteristic Habitat for Vernal Pool Invertebrates**
- e. **Maintain Characteristic Habitat for Vernal Pool Amphibians**

The following sequence is used to present and discuss each of these five functions.

**Definition:** defines the function and identifies an independent quantitative measure that can be used to validate the functional index.

**Rationale for selecting the function:** provides the rationale for why the function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.

**Characteristics and processes that influence the function:** describes the characteristics and processes of the wetland and the surrounding landscape that influence the function and lay the basis for the selection and description of the model variables.

**Description of model variables:** defines and discusses model variables and describes how each model variable is measured.

Functional capacity index: describes the assessment model from which the functional capacity index is derived and discusses how model variables interact to influence functional capacity.

### **Function 1: Surface Water Storage in Pool Basin**

#### **Definition**

This function is the capacity of the pool basin to seasonally pond and retains surface water for long duration (7 days to 1 month). The dominant water source is from precipitation either directly into the pool or via subsurface flow from the sides of the vernal pool basin. An independent measure of this function is cubic meters of water per unit of surface area.

#### **Rationale for Selecting the Function**

Vernal pools represent shallow depressions in the landscape. They are underlain with a shallow hard claypan that restricts downward, and often, lateral water movement within the substrate. This natural depression and associated restricting layer provide a natural water storage system. Most (77.9 percent) of the vernal pools observed in this study were isolated depressions ideally suited to perform this function.

The capacity of the vernal pool to pond water creates a temporary, seasonal pool of water necessary for the growth, development, and reproduction of vernal pool flora and fauna. Many aquatic invertebrates develop in vernal pools during ponding, consequently providing important food reserves for many migrating and nesting shorebirds and waterfowl. The ability to pond water may also influence other important wetland functions such as cycling of nutrients. Changes in the morphology

of the vernal pool basin or surrounding landscape by deep ripping, land leveling, or other disturbances can result in accelerated transport of water to the pool or diversion of water away from the pool. Onsite effects of this function result in the creation of temporary, seasonal pools of water necessary for the growth, development, and reproduction of vernal pool flora and fauna. Offsite effects are the development of propagules for germination of adjacent vernal pools and the development of invertebrates that can be transported offsite. Many waterfowl utilize invertebrates from within the pools but then migrate offsite for reproduction.

### **Characteristic Processes that Influence the Function**

The ability of a hard claypan vernal pool to perform this function is related to characteristics of the adjacent watershed and characteristics within the basin. Disturbances or alterations within the watershed can influence the transport of water to or away from the pool. Ditching, land leveling, and construction of diversions such as roads or berms can impede water transport to the pool and excavation of the perimeter of the pool itself can cause the pool to drain, preventing the successful retention of surface waters. There are also attributes within the pool that can influence the ability of the wetland to perform this function. Disruption of the continuity or permeability of the substrate or durapan can alter the ability of the pool to retain surface water. Changes in duration and depth of the pool can decrease the pool's ability to perform this function. The shape and slope of the edge of the pool can also affect the ability to store surface waters. Variables selected to characterize the functional capacity of the wetland are described below.

## Description of Model Variables

**Upland land use ( $V_{UPUSE}$ ).** This variable represents a measure of the types and severity of disturbances that alter runoff into or away from a vernal pool watershed. The concept is that any deviation from an undisturbed environment is likely to alter the functional capacity of the wetland to perform this function. The concept is not to maximize the surface water storage of the wetland; more is not necessarily better. The objective is to provide water at a frequency and duration “typical” of naturally occurring, undisturbed vernal pools in order to maintain a fully functioning ecosystem. Too much water or too little water, relative to what is normally provided to a vernal pool is a deflection from reference standard conditions and is scaled to less than 1.0 depending on the magnitude of the deflection.

The approach used to scale this variable is based on the *rational runoff method* and is referred to as the *rational equation* in Fetter (1994). The equation considers land use types that are assigned a rational runoff coefficient value, and, when combined with rainfall intensity, area of the watershed, and a constant are used to compute runoff from different landscapes. The rational equation is most valid when used to analyze small drainage basins of 100 ha or less (Fetter 1994); vernal pool watersheds are certainly smaller than this threshold. Runoff coefficients used by Dunne and Leopold (1978) approach 1.0 when runoff would be expected to be high, such as in high value business districts and near zero (0.1) when runoff is expected to be low, like in unimproved land. However, functional indices in the HGM Approach are scaled in the inverse of those by Dunne and Leopold (1978) such that indices assigned a 1.0 reflect relatively undisturbed environments, hence reduced runoff.

Using subindices assigned by the A-Team and the inverse of several land use categories by Dunne and Leopold (1978), Table 17 was developed to provide the end user with variable subindexes for upland land use. The end user should use the minimum variable subindex (indicator of the greatest runoff coefficient) of any of the land use categories in the watershed.

Table 17. Current land use in the vernal pool watershed and the variable subindex score to compute  $V_{UPUSE}$ .

Land Use in the Watershed	Variable Subindex
Urban Areas	
Business areas: high-value districts	0.15
: neighborhood districts	0.40
Residential areas: single-family dwellings	0.60
: multiple-family dwellings	.42
Industrial areas: light	0.35
: heavy	0.75
Rural Areas	
Loams and similar soils: cultivated	0.60
: pasture	0.65
: land leveled or scraped	0.50
Heavy clay soils: cultivated	0.50
: pasture	0.55
: land leveled or scraped	0.25
Undisturbed grassland or no alterations to runoff	1.00

Modification of Dunne and Leopold (1978).

**Outlet of the vernal pool ( $V_{OUT}$ ).** This variable represents a measure of changes in the outlet of the vernal pool. Approximately 78 percent of the vernal pools sampled were isolated pools with no discernible outlets. However, connecting one pool to the next via a shallow ditch may drain vernal pools and eliminate the ability of a pool to perform this function. Therefore, in order to capture this potential disturbance, one should first calculate the maximum depth of the pool by using a line level stretched from the edge of the pool near the mima mound to the deepest point in

the pool. Then one should measure the depth of the invert of the ditch using the line level as a datum. Then divide the vertical distance from the line level to the invert of the ditch by the maximum depth of the pool to compute the percent depth the ditch is of the maximum depth of the pool. For example, if the maximum depth of the pool is determined to be 20 cm and the depth of the ditch relative to the edge of the pool is 10 cm, then the percent would be  $10/20 = 0.5 = 50$  percent. The depth of the ditch is 50 percent of the maximum depth of the pool. Using Figure 14, one can then determine the variable subindex by reading the percent on the x-axis and determining the variable subindex on the y-axis as 0.5. As the depth of the ditch approaches the maximum depth of the pool, the variable subindex approaches 0.0. If no ditch is present, then the variable subindex is 1.0.

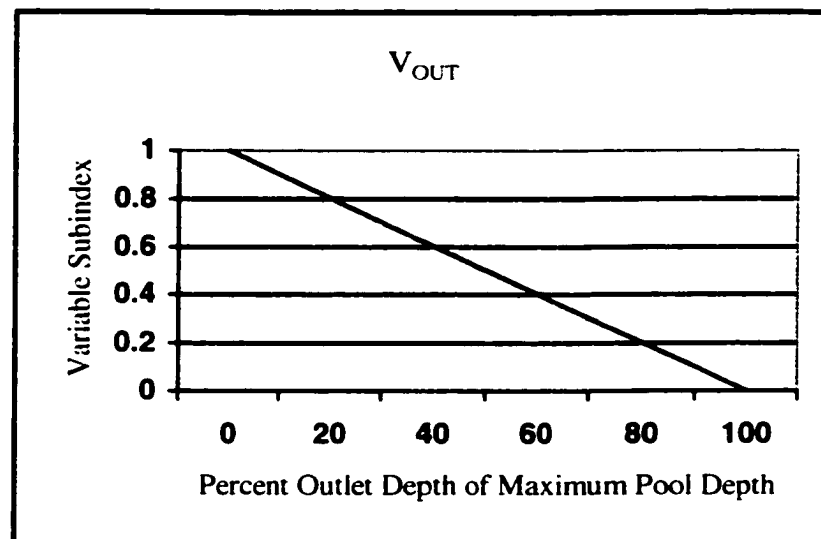


Figure 14. Relationship between the percent of pool maximum depth and outlet depth to functional capacity.

**Slope of the vernal pool edge ( $V_{ESLOPE}$ ).** This variable provides a measure of the slope of the vernal pool within two meters on each side of the interface between the pool and surrounding upland. Alterations of the surrounding vernal pool

landscapes tend to reflect land-leveling practices whereby the mima mounds are often leveled and the associated soils deposited into the vernal pools. Some vernal pool watersheds or the pools themselves have also been scraped and leveled to facilitate draining the landscape. Historically, many of the vernal pool complexes were also farmed with the mima mounds leveled and soils deposited within the pools.

Extremely shallow vernal pools with nearly flat slopes were observed at the more severely degraded sites at Teigert Aggregate and Mountain Top and at those scraped on the western end of the Elliott Ranch site. Reference standard pools at Sunrise Douglas had slopes averaging greater than 4.5 percent but those disturbed pools had slopes averaging less than 1.0 percent (Figure 15).

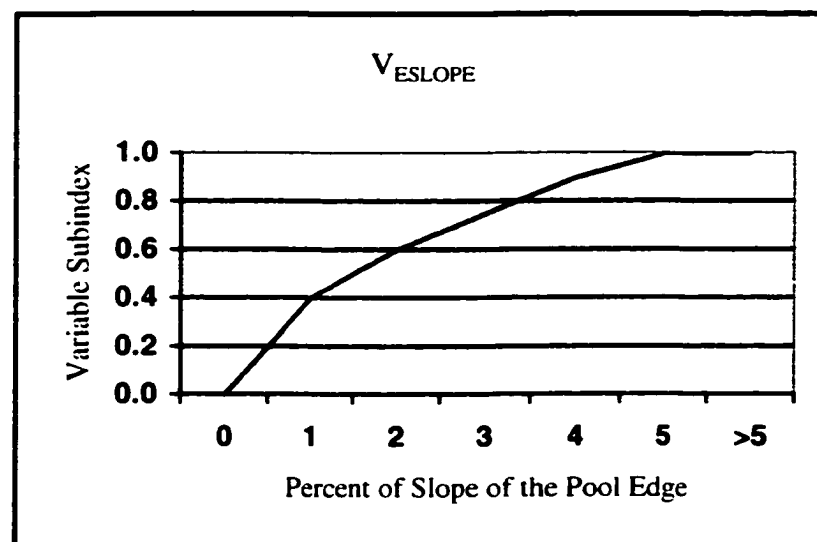


Figure 15. Relationship between the percent slope of the edge of the pool and functional capacity.

**Presence of a durapan or other restricting layer ( $V_{DURP}$ ).** A durapan is a subsurface soil horizon that is cemented by illuvial silica to the degree that less than 50 percent of the volume of air-dry fragments slake in water or during prolonged

soaking in acid. Durapans vary in the degree of cementation. The presence of a durapan or similar restricting layer is required for a vernal pool to occur. Depth to the durapan or other restricting layer varied at the vernal pools sampled from 13 to 91 cm within the pools and 20 to 104 cm outside the pools, with depths nearly always greater outside the pools (Figure 16). The only pools that did not exhibit the presence of a durapan or restricting layer were at Mountain Top, due to the deep ripping prior to data collection. There was no discernible relationship between the disturbance quotient and the depth of the durapan; it seemed that if the durapan was present, the vernal pool was able to store water. Therefore, the variable subindex is categorical; if a durapan or similar restricting layer is present the subindex is a 1.0, if absent it is a 0.0.

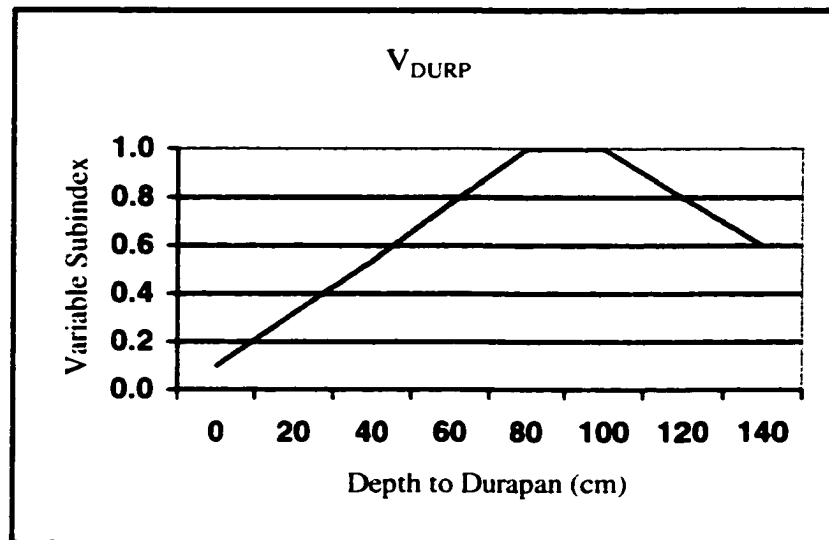


Figure 16. Relationship between depth of the durapan and functional capacity.

### Functional Capacity Index

The assessment model for calculating the functional capacity index (FCI) for Function 1: "Surface Water Storage in Pool Basin," is as follows:

$$FCI_{SW} = ((V_{UPUSE} + V_{ESLOPE}) / 2) * (V_{OUT} * V_{DURP})^{1/2}$$



The model is structured in two components that are additive in the model and two components that are multiplicative. One additive component incorporates variables to assess the capacity of the surrounding landscape to transport water to the wetland and the other component characterizes the slope of the edge of the pool. These two factors influence water movement to the wetland ( $V_{UPSUE}$ ) and the ability to retain the water once it reaches the wetland ( $V_{ESLOPE}$ ). The vernal pool may be able to perform the function if one of the two factors goes to 0.0 but not if both go to zero, particularly if the slope is so flat that water cannot be retained in the pool. Two other components in the model ( $V_{OUT}$  and  $V_{DURP}$ ), however, are multiplicative because these two components of the model are required to be less than zero. If either of these variable subindices goes to 0.0, then the vernal pool will be unable to store surface water. If an outlet is constructed that is as deep as the lowest point of the pool, no water can be stored. Also, if the durapan is destroyed, as was the case at Mountain Top, the pool not only cannot store water, it cannot be restored. If either or both the  $V_{OUT}$  or  $V_{DURP}$  is 0.0, the FCI becomes 0.0.

### Function 2: Subsurface Water Exchange

#### Definition

Subsurface water exchange is the capacity of the subsurface area above the restrictive layer to hold water and allow the exchange of water between the pool basin and surrounding landscape (pool banks and mound areas). A quantitative measure of this function is the available water capacity within the pool basin substrate as measured by centimeters of water per centimeter of soil.

## **Rationale for Selecting the Function**

Vernal pool plants have adapted to the rapid loss of surface waters during early spring, but the continued availability of the substrate to prolong drying and therefore prolong plant development and maturation. The high clay content of vernal pool substrates holds water long after the surface water has been lost. Greater water-holding capacity of the substrate is associated with a higher ability to recharge the pool basin from the surrounding area and with dynamic water exchange between the pool basin and the surrounding area.

The onsite effects of losing this function would be a decreased ability to support vernal pool vegetation and other aquatic organisms that benefit from prolonged availability of water in the pool. The offsite effects of losing this function could be the change in plant species immediately adjacent to the edge of the pool since these plants also benefit from water stored within the pool substrate. If the substrate above the restrictive layer is scraped or altered, the depth of the ability of the substrate to provide this function is impeded. Deposition of fill material within the pool may also impede the ability of the substrate to provide moisture that supports vernal pool vegetation.

## **Characteristics and Processes that Influence the Function**

Soil depth and texture above the restricting layer have the greatest influence on the ability of the vernal pool substrate to prolong drying and provide an extended period of time for moisture to the plants within the pool basin and the surrounding landscape. The number and depth of the soil horizons will also influence the ability to retain moisture in the pool substrates. Different types of disturbances within the pool

can alter the ability of the substrate to perform this function. Activities that change the compaction of the soil will impede the ability to retain and provide water within the substrate. Excavation of the substrate reduces the depth of the water holding materials, thereby decreasing the ability to provide moisture.

## Description of Model Variables

**Available water capacity within the pool basin ( $V_{BEDAWC}$ ).** Available water capacity is a measure of the ability of soils to hold water available for use by plants. It is commonly defined as the difference between the amount of soil water at field capacity and the amount at wilting point and is commonly expressed as inches of water per inch of soil (Tugel et al. 1993). Units expressed in this document are centimeters of water per centimeter of soil. The available water capacity of soils in the pool basin is determined by digging a hole in the vernal pool. One should then measure the depth of the different soil horizons and calculate the available water capacity of each soil horizon by comparing the capacities in the county soil survey (Tugel et al. 1993). Once the depths and available water capacity are determined for the vernal pool soils in the basin, they are compared to those expected from a similar soil type from the vernal pool basin. This difference between the observed and the expected is then compared to Figure 17 to compute the variable subindex. An example of how to calculate the available water capacity is provided below:

Pool 15 at the Elliott Ranch vernal pool complex had been scraped about 15 years ago to provide materials for Interstate 5 from Sacramento. The soils were identified from the soil survey as a San Joaquin – Galt complex with 0 – 3 percent slopes. Galt was expected in the pool basins and San Joaquin in the mounds between

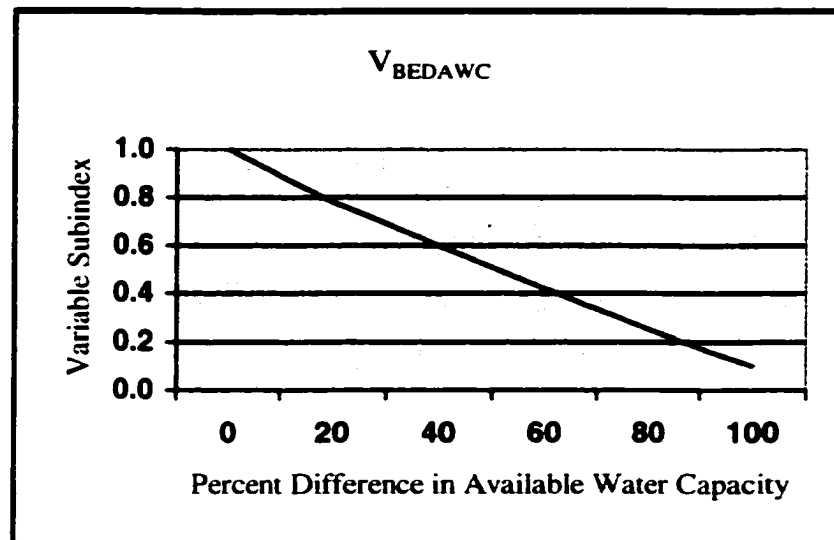


Figure 17. Relationship between the difference in observed available water capacity in the pool basin and the expected available water capacity for the soil type in the pool basin.

vernal pools. Inspection of Pool 15 revealed that there were three soil horizons above the durapan with the following characteristics:

Horizon	Depth (cm)	Soil Texture	AWC (cm/cm)	Total AWC
Ap	0 – 15	SC	0.100	$15 \times 0.1 = 0.150$
BC	15 – 20	C	0.135	$5 \times 0.135 = 0.675$
C	20 – 36	C	0.135	$16 \times 0.135 = 2.16$
durapan	36			

Total AWC above the restrictive layer (durapan) in the pool is 2.985 cm.

However, the total available water capacity for a typical Galt soil, based on information from the soil survey (Tugel et al. 1993), is 10.57 cm with a durapan expected at about 81 cm. Therefore, the scraped hard claypan vernal pool at Elliott Ranch has about 28.2 percent ( $2.985 / 10.57$ ) of the capacity of a typical Galt soil and would therefore have a difference of  $100 - 28.2 = 61.8$  percent of that expected. This percent difference would be read directly from the chart in Figure 17, resulting in a

variable subindex score of about 0.4 for the available water capacity in the pool basin. This subindex score, along with subindex scores for other variables, is then used in the functional capacity index model to compute a functional capacity index for this function.

#### **Available water capacity in the banks or sides of the pool basin**

( $V_{\text{BANKAWC}}$ ). The concept for this variable is the same as for the bed of the pool basin except that the available water capacity is determined from the adjacent edge of the pool. The soil profile should be characterized within one meter outside of the edge of the pool; the computation is the same as that within the pool basin. One should note, however, that the soil survey may indicate a different soil type outside the vernal pool so the standard for comparison may be different outside the pool. Again using the characteristics of the soil profile outside of the pool, calculate the available water capacity adjacent to the pool and compare to the “typical” soil profile in the mima mounds. Compute the percent difference from the soil survey and determine the variable subindex from Figure 18.

#### **Functional Capacity Index**

The assessment model for calculating the functional capacity index (FCI) for Function 2: “Subsurface Water Exchange,” is as follows:

$$FCI_{\text{SSWE}} = ((V_{\text{BEDAWC}} + V_{\text{BANKAWC}}) / 2)$$

The variable subindex score for the pool basin is then used, along with the variable subindex score for the vernal pool bank, to calculate the functional capacity of subsurface water storage for the vernal pool. An average of the two subindexes is computed to represent the functional capacity.

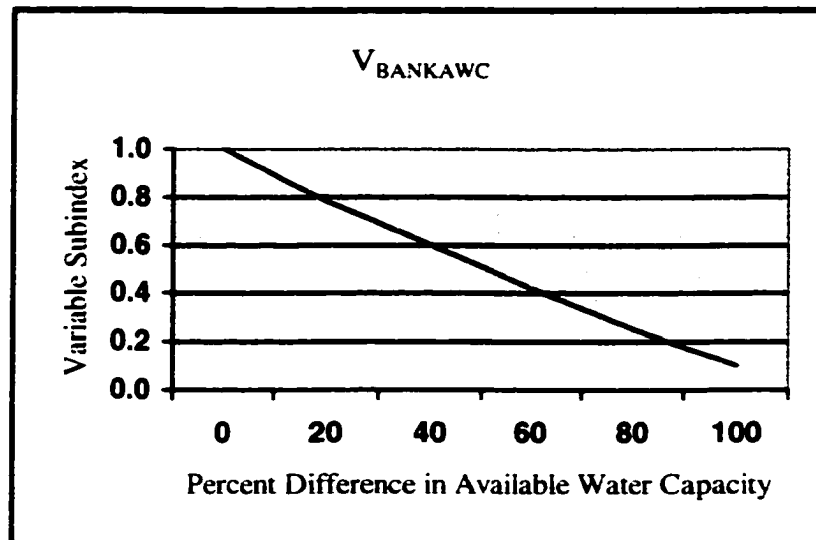


Figure 18 . Relationship between the difference in observed available water capacity in the pool basin and the expected available water capacity for the soil type in the pool basin.

### Function 3: Maintain Characteristic Habitat for Vernal Pool Vegetation

#### Definition

This functions is the capability of perpetuating predominantly native vegetation through a variety of morphological, reproductive, and developmental adaptations and spore/seed dispersal mechanisms in response to the extreme environmental conditions of wetting and drying. Emphasis is on the dynamics and structure of the vegetation as revealed by species phenology, composition, and abundance. A quantitative measure of this function is a similarity index derived from the total plant community within the pool basin.

#### Rationale for Selecting the Function

Vegetation characteristic of vernal pools provides important habitat for feeding, breeding, and resting by many waterfowl and shorebirds during migration

through the Pacific Flyway. Vegetation provides the carbon source for many of the invertebrates that are also fed upon by these same avifaunal groups. Many of the vegetative species are also listed as threatened or endangered, so their existence is often restricted to vernal pools. Destruction of these sensitive habitats results in the loss of many plant species with very limited distribution.

### Characteristics and Processes that Influence the Function

Holland and Jain (1977) refer to the concentric circle distribution of the plant communities as pools dry. They found that vernal pools have generally resisted invasion from outside species because of the unique and challenging habitat. They found that very few introduced species have been successful in the pool environment. In the grasslands, about 38 percent of the species are introduced whereas the pool flora contains only 5-10 percent introduced species.

The distribution of vernal pool vegetation is influenced by many factors external to the pool, such as certain types of land uses, but primarily with factors directly associated with the vernal pool basin. Therefore, the vegetation model incorporates the measures of land use, intensity of cattle grazing, the presence or absence of an outlet, and the depth to the durapan as disturbance factors. Also included in the model are characteristics of the bed of the vernal pool basin, which serves as a reservoir for soil moisture. Finally, the model considers the percent cover of vegetation and the percent native species. Each variable is discussed below.

### Description of Model Variables

**Upland land use ( $V_{UPUSE}$ ).** This variable represents a measure of the types and severity of disturbances that alter runoff into or away from a vernal pool and can

therefore influence plant composition and distribution. Too much water or too little water can change the character of the plant community. Using the variable subindex scores in Table 17, one can compute an index from 0.0 to 1.0.

**Cattle grazing intensity ( $V_{\text{GRAZ}}$ ).** This variable is discussed as part of the disturbance quotient in Chapters 4 and 5. Intensity of cattle grazing is scored based on the bar chart in Figure 19. Light grazing is less detrimental to the plant community than no grazing, since light grazing prevents an excess accumulation of litter, which can tend to smother early plant growth and cause detrimental soil thermal properties. Each of the levels of intensity of cattle grazing are defined (Glossary Revision Special Committee 1989) in the Glossary in Appendix A.

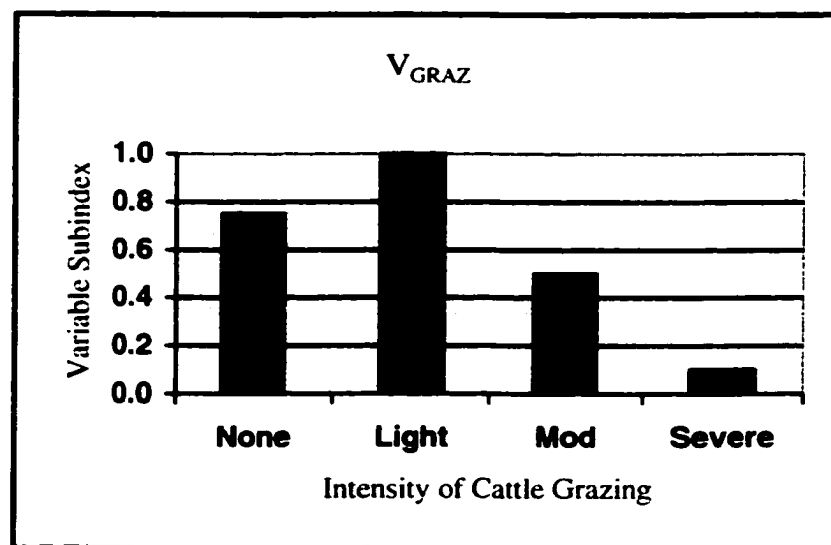


Figure 19. Relationship between the intensity of cattle grazing in the vernal pool basin and the functional capacity.

**Available water capacity within the pool basin ( $V_{\text{BEDAWC}}$ ).** Available water capacity within vernal pool soils can have a considerable influence on plant composition. If the soils retain water within the substrate, many plants can continue to flourish even though surface water is not available. Factors such as scraping or



compaction can alter the ability of soils to retain moisture, which would cause them to deviate from those relatively undisturbed soils in vernal pools. Using Figure 17, one can develop a variable subindex based on the difference between the observed available water capacity in the vernal pool and that expected within a relatively undisturbed vernal pool soil.

**Outlet of the vernal pool ( $V_{OUT}$ ).** This variable provides another means to detect disturbance but also provides a means to assess the permanence of water within the pool. Unlike some other functions such as Surface Water Storage, which are unlikely to occur if an outlet is present, many vernal pool plant species would still occur in the pool basin, just not as predominantly as without the outlet. Soils high in clay content, like those in vernal pools, would still retain moisture and allow some plant species to develop. However, the presence of an outlet would enhance the opportunity for plant species from the mima mounds to more effectively compete with vernal pool species, thus resulting in a change in plant composition and distribution. Using Figure 14, one can determine the appropriate variable subindex to use in the model.

**Presence of a durapan or other restricting layer ( $V_{DURP}$ ).** A durapan will retain moisture within the hard claypan vernal pool and enhance growth of vernal pool plant species. The presence of a durapan is very important in maintaining a viable vernal pool plant community because it is influential in retaining both surface and subsurface waters. One should use Figure 16 to compute the appropriate variable subindex to use in the model, “Maintain Characteristic Habitat for Vernal Pool Vegetation.”

**Percent native plant species ( $V_{\text{NATIVE}}$ ).** The percent of native plant species was computed by dividing the number of native plant species in the vernal pool by the sum of all the plant species. The percent of native plant species varied from an average of 16 at Valensin Ranch and 14 at Sunrise Douglas, both sites considered to be reference standard sites. Conversely, the ratios averaged 0.73 and 0.61 at Teigert Aggregates and Mountain Top, respectively. The variable subindex is computed from Figure 20.

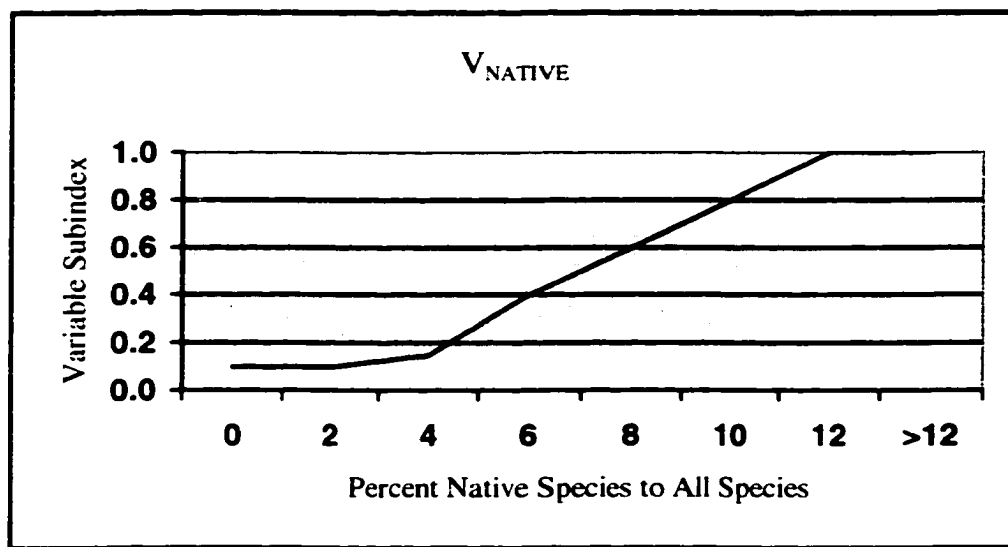


Figure 20. Relationship between the percent of native plant species within the vernal pool and the functional capacity.

**Percent cover of plant species ( $V_{\text{PCTCOV}}$ ).** The percent of cover of plant species indicates the distribution of plants within the vernal pool. Although it can include both native and non-native plant species, it can indicate favorable conditions for plant growth. Other factors within the model indicate the suitability of the site to support plant species indicative of relatively undisturbed vernal pool habitats. Percent cover was fairly high at all sites, but less at the constructed pools and at more

degraded sites. Figure 21 illustrates the relationship between the functional capacity and the percent cover within the vernal pools.

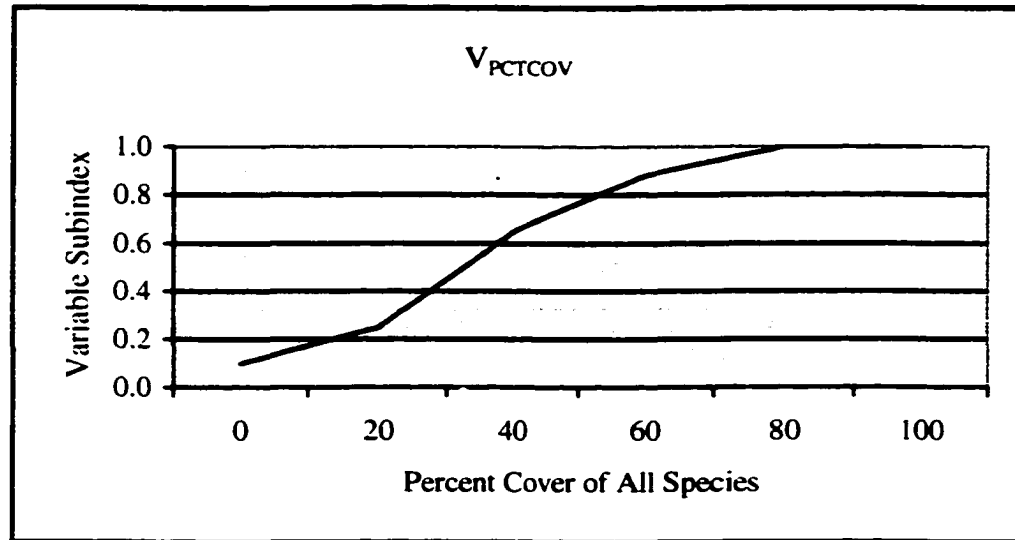


Figure 21 . Relationship between the percent cover of plant species and functional capacity.

### Functional Capacity Index

The model for Function 3 “Maintain Characteristic Habitat for Vernal Pool Vegetation,” incorporates characteristics outside the vernal pool and within the pool. It also incorporates the composition and distribution of vernal pool species observed during data collection. The assessment model for calculating the functional capacity index (FCI to Maintain Characteristic Habitat for Vernal Pool Vegetation) is as follows:

$$FCI_{MCHVPV} = (((V_{UPUSE} + V_{GRAZ} + V_{BEDAWC} + V_{OUT})/4) + (((V_{NATIVE} + V_{PCTCOV}) / 2) / 2) * (V_{DURP}))$$

The model initially considers four factors that could reflect disturbance and averages these variables. It then considers the characteristics of the plants present at

the site and again averages these two variables. These two components of the model are then averaged. Finally, the depth of the durapan is added as a multiplicative component since the pool will not remain as a viable vernal pool if the durapan has been destroyed. Only if there is no durapan is the FCI likely to go to 0.0, since most other components will likely exist at some level.

#### **Function 4: Maintain Characteristic Habitat for Vernal Pool Invertebrates**

##### **Definition**

This function is defined as the capability of a wetland to perpetuate invertebrate populations through a variety of reproductive and developmental adaptations in response to the extreme environmental conditions of wetting and drying. Emphasis is on the dynamics and structure of the invertebrate ecology of vernal pools as revealed by habitat conditions. A quantitative measure of this function would be the number and diversity of invertebrates present per cubic meter of water during the aquatic phase.

##### **Rationale for Selecting the Function**

Vernal pools support a wide variety of invertebrate species. Many of these species are listed as threatened or endangered and occur on very limited habitats within vernal pool complexes. The high levels of protein and calcium in these organisms also provide an important food source for many waterfowl and shorebirds migrating along the Pacific Flyway during the spring (Eulis and Grodhaus 1987). They are consumed by many amphibians and play an important part in the complex food webs within vernal pools. King et al. (1996) found 67 species of crustaceans in a

study of vernal pools in northern California and felt that almost half may be previously undescribed species. They also found that many of the crustaceans were highly endemic, relatively rare, and previously unknown species, thus suggesting a relatively unique habitat has had limited investigations.

### **Characteristics and Processes that Influence the Function**

The study by King et al. (1996) included an extensive survey of crustaceans in 58 vernal pools at 14 sites in northern California and found that there was a positive correlation between species richness and both depth and surface area. The relationship was explained in terms of the extended hydroperiod in larger pools, which resulted in an increased ability of species with slower developmental rates to reach maturity in long-lived pools. Also, an extended hydroperiod provides greater time for temporal resource partitioning of a diverse invertebrate community. The larger size of pools provides greater spatial habitat heterogeneity. Differences in species composition among pools correspond with physical and chemical aspects of the habitat including depth, solute concentrations, elevation, and biogeographic region. King et al. (1996) state that the best strategy for maintaining vernal pool habitats is to include many pools at each site, multiple sites of each habitat type, and all identified types.

Gallagher (1996) studied branchiopods in northern California and examined pool depth, area, and volume in relation to species occurrences. Pool area and volume were not considered as important as pool depth in influencing invertebrate composition. Duration of flooding for *Branchinecta lynchi* to complete its life cycle was between 3 and 14 weeks. Most pools containing *B. lynchi* had a duration of

7 weeks, with brood females occurring within 6 weeks early in the season and within 2 weeks later in the season when temperatures were higher. *Linderiella occidentalis* and *Lepidurus packardii* required deeper pools with durations greater than 7 weeks. Gallagher (1996) also observed a second hatch in March in those pools with sufficient water. Pools with these species were found to be deeper, larger, and have more volume than pools without the species. Surface area and volume were thought to be less important than depth. Thiery (1991) also found depth important for similar species in temporary ponds in Morocco.

Szalay (1996) examined the effect of mowing on invertebrate populations and found that mowing may actually increase invertebrate densities, particularly for benthic species. He also found that mosquito populations were usually lower in mowed areas. No mowing was observed in any of the vernal pools or complexes sampled in this study, however, so this variable could not be considered in construction of the models.

## Description of Model Variables

**Maximum depth of the vernal pool ( $V_{MAXDEPTH}$ ).** The maximum depth of the vernal pool in centimeters is measured using a line level or other level vertically from the edge of the pool to the deepest point within the pool as determined by ocular estimate or more precise means (elevation survey equipment) if available. Maximum depth varied from nearly 10.5 cm at Teigert Aggregates, one of the complexes considered among the most degraded, to 45.8 cm at the reference standard sites at Sunrise Douglas. The relationship between maximum depth and the functional capacity index is presented in Figure 22.

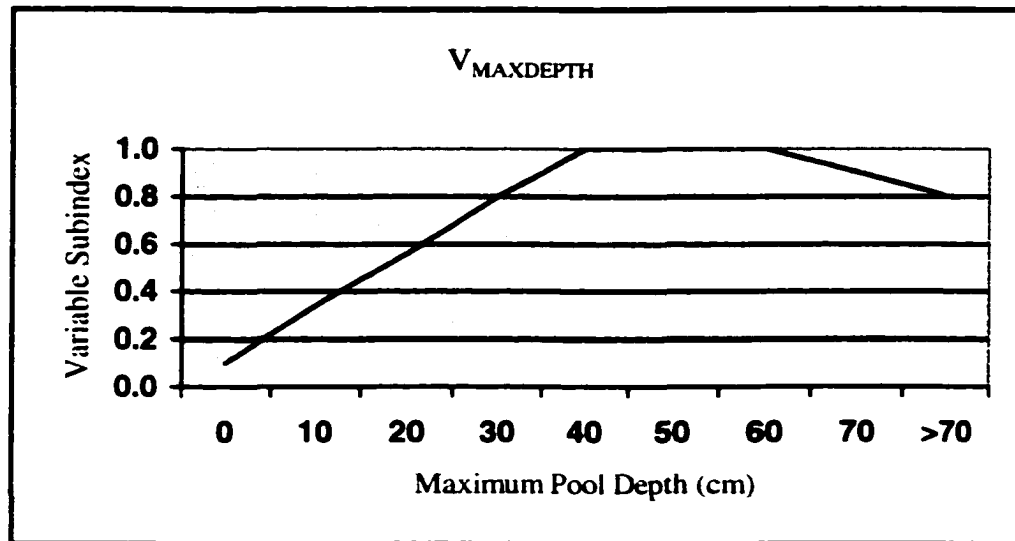


Figure 22. Relationship between the maximum depth (cm) of the vernal pool and functional capacity.

**Area of the vernal pool ( $m^2$ ) ( $V_{PAREA}$ ).** The pool area provides an indication of the duration of ponding. The vernal pools in this study had a wide distribution of sizes, so the variable is scaled based on the average for some of the complexes. This is one variable that is scaled for the function but not indicative of disturbance since both small and large vernal pools can be degraded or relatively undisturbed. Those pools that seemed to be larger also tended to have a greater volume of water, which would prolong ponded conditions. Pools at Teigert Aggregates averaged  $67 m^2$  and those at Mountain Top averaged  $279 m^2$ , so these represent the lower end of the scale, whereas pools at the reference standard sites at Sunrise Douglas averaged  $440 m^2$  and represent the upper end of the scale. This results in a fairly narrow range as indicated in Figure 23 below. A better estimate of the functional capacity of the site would be duration of ponding, but that was not computed in this study.

**Percent cover of plant species ( $V_{PCTCOV}$ ).** The percent cover of plant species indicates the carbon source that can be utilized by plankton in the vernal pool. This

food source is then available for utilization by many aquatic macroinvertebrates. The variable is scaled in Figure 21.

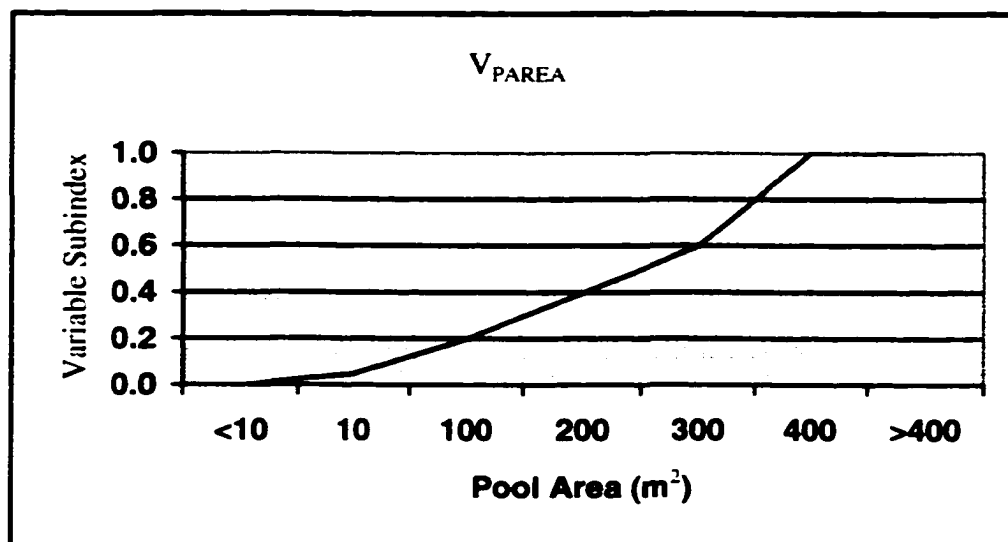


Figure 23. Relationship between pool area ( $m^2$ ) and functional capacity.

**Outlet of the vernal pool ( $V_{OUT}$ ).** This variable measures the water retention capacity of the vernal pool. Aquatic invertebrates must have ponded water and it must remain in the pool for a sufficient period of time for the invertebrates to complete their life cycle. That duration varies from one species to the next, but is generally a minimum of three weeks. If an outlet is present and capable of completely draining the wetland, the pool will not be capable of providing this function. The relationship between this function and the depth of the outlet is presented in Figure 14.

**Presence of a durapan or other restricting layer ( $V_{DURP}$ ).** A durapan provides a restrictive layer in the soil and impedes downward movement of water. It is a critical component of vernal pool ecosystems. If the durapan or restrictive layer of a vernal pool is destroyed, the surface water will be lost and habitat for aquatic



invertebrates will be destroyed. The relationship of this variable to the functional capacity of the vernal pool is presented in Figure 16.

### **Functional Capacity Index**

The assessment model for calculating the functional capacity index (FCI) for Function 4: “Maintain Characteristic Habitat for Vernal Pool Invertebrates,” is as follows:

$$FCI_{MCHVPI} = (V_{MAXDEPTH} + V_{PAREA} + V_{PLTCOV}) / 3 * (V_{OUT} * V_{DURP})$$

The model contains two major components. One component is an average of characteristics of the pool that provide adequate onsite habitat attributes. This component captures aspects of the duration of flooding and carbon sources that drive the ecological engine. The second component examines potential disturbance factors that could damage the vernal pool and impede retention of surface waters and therefore, aquatic invertebrates. This second component is multiplicative because the two variables are critical to sustaining a viable invertebrate community; without surface water, the invertebrates will not survive.

### **Function 5: Maintain Characteristic Habitat for Vernal Pool Amphibians**

#### **Definition**

This function is defined as the capability a hard claypan vernal pool can provide for life history requirements for populations of vertebrate species that rely upon vernal pools for habitat and for activities such as reproduction, development, and/or feeding. This function is primarily an assessment of amphibian vertebrates and a quantitative measure of this function is the number of amphibians and diversity of

species present in the hard claypan vernal pool per month during the aquatic and drying phases.

### **Rationale for Selecting the Function**

Vernal pools provide habitat for many amphibian species including the Pacific tree frog, *Hyla regilla*, spade-foot toad, *Scaphiopus hammondi*, western toad, *Bufo boreas*, and to a lesser extent, the California tiger salamander, *Ambystoma californiense*. These species and other amphibians utilize vernal pools for several life requisites including breeding, feeding, and resting. Although amphibians are not restricted to vernal pools, vernal pools often provide the only aquatic habitat in some landscapes so their presence can be very important. Since vernal pools dry each year, they provide a rather unique aquatic environment that lacks many of the predatory species such as large bullfrogs, crawfish, and fish that can limit or eliminate viable amphibian populations.

### **Characteristics and Processes that Influence the Function**

During the period from 1949 to 1958, Minton (1968) noted a decline in reptiles and amphibians near an urban area around Indianapolis, Indiana. He felt that the modifications of the aquatic habitat appeared to be the most important factor in the decline of the species. Changes in landscape characteristics impeded population development.

Loredo and Van Vuren (1996) assessed habitat for a population of California tiger salamanders (*Ambystoma californiense*) during migration and found that rainfall was the only factor that seemed to relate to population numbers during the same season. Variation in numbers could not be attributed to any environmental variables

measured. Migration begins when pools fill with the onset of the rainy season. California tiger salamanders require considerable water so they are most prevalent in larger, deeper vernal pools. Juvenile production has been positively correlated with pond duration in other studies (Shoop 1974; Semlitsch 1987). Pond duration can also influence timing of metamorphosis.

Amphibians may also move from pool to pool as smaller pools dry, so the presence of shallow swales connecting pools could be an important attribute of vernal pool complexes. Also the distance between pools can influence the ability of vernal pool complexes to support amphibian populations. Taylor et al. (1993) define landscape connectivity as the degree to which the landscape facilitates or impedes movement among resource patches.

### Description of Model Variables

**Disturbance quotient ( $V_{DQ}$ ).** This variable measures the types and severity of disturbances that can alter amphibian movements and survival. Human disturbances can have a considerable influence outside of the vernal pool as well as more directly within the pool itself. This variable is discussed in Chapter 5 and provides a scale of disturbance from 0.0 for severely disturbed areas to 1.0 for no disturbance.

**Distance from the edge of one pool to the edge of the nearest pool ( $V_{E2E}$ ).** This variable indicates the distance that an amphibian might have to travel to reach another vernal pool for meeting different life requisites. It also provides an indication of the habitat diversity within a complex and proximity of different pool depths and

sizes. The relationship of this variable to the functional capacity is provided in Figure 24.

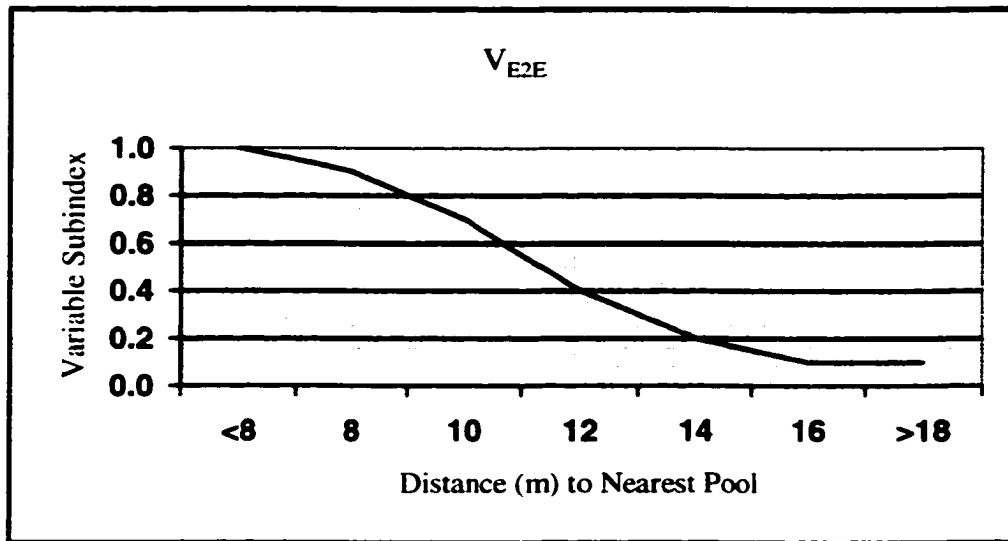


Figure 24. Relationship of the minimum distance (m) from the nearest vernal pool.

**Pool interconnectedness ( $V_{PCON}$ ).** This variable captures the interconnectedness of vernal pools in a complex. Those pools connected to other pools via a shallow swale are assigned a higher score than isolated pools. However, neither type pool is scored low so that other factors primarily influence the overall vernal pool functional capacity index. This variable is included to provide a slightly higher score for those pools connected to adjacent pools. The relationship of pool interconnectedness and functional capacity is presented in Figure 25.

**Maximum depth of the vernal pool ( $V_{DEPTH}$ ).** The maximum depth of the vernal pool in centimeters indicates the duration of vernal pool ponding. Several researchers, as indicated above, found that prolonged duration in excess of several weeks was necessary for invertebrates to colonize a pool and complete their life cycles. Amphibians require a longer period to complete their life cycles but the

invertebrate populations can help sustain the early stages of development. The relationship of the maximum depth of the vernal pool to the functional capacity is provided in Figure 14.

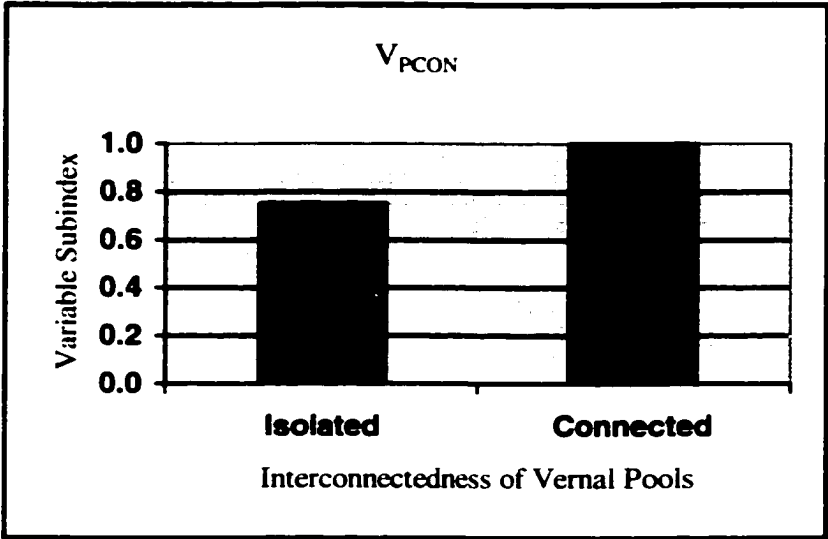


Figure 25. Relationship between the interconnectedness of vernal pools and functional capacity.

**Percent cover of plant species ( $V_{PCTCOV}$ ).** Plant cover provides habitat for many amphibian species and increases habitat diversity for amphibians and other organisms that are fed upon by amphibians. Plants also provide carbon that enhances production of many aquatic invertebrates. The relationship of the percent plant cover to functional capacity is presented in Figure 21.

**Outlet of the vernal pool ( $V_{OUT}$ ).** This variable is intended to capture disturbance due to draining the vernal pool. If an outlet is constructed to remove water from the pool, amphibian populations will suffer, forcing organisms to move or die. The relationship between the outlet of the vernal pool and the functional capacity is illustrated in Figure 14.

**Presence of a durapan or other restricting layer ( $V_{DURP}$ ).** Depth to the durapan indicates disturbance and the ability of the vernal pool to pond water. Retention of water within the vernal pool is critical for survival of amphibian species. The relationship of the depth of the durapan to functional capacity is presented in Figure 16.

### **Functional Capacity Index**

The assessment model for calculating the functional capacity index (FCI) for Function 5: “Maintain Characteristic Habitat for Vernal Pool Amphibians,” is as follows:

$$FCI_{MCHVPA} = (((V_{DQ} + V_{E2E} + V_{PCON})/3) + ((V_{DEPTH} + V_{PLTCOV}) / 2)) / 2) * (V_{OUT} * V_{DURP})^{1/2}$$

The model has three major components. The first component examines disturbances primarily in the complex and the interspersions of pools to reflect characteristics primarily within the surrounding landscape. The second component examines attributes within the pool such as depth and cover that influence amphibian habitat. The third component assesses disturbance factors that represent potential changes in the habitat and threats to amphibian species.

The assessment models presented in this chapter represent most, but not all, functions that vernal pools may provide. Other scientists and this author could likely identify other functions at different levels of detail, but scaling those functions to the reference data set poses greater challenges. Models must be designed that require very little data but can still provide consistent results. They must be easily implemented in the field during any time of year. The models presented here

represent a first attempt at assessing vernal pool wetlands using data collected in the Central Valley of California. This author is aware of another effort to develop wetland assessment models for vernal pools in southern California. Data collected in this study should serve as the foundation for that study, so that upon completion of the study in southern California, better, improved models should be constructed. Science builds upon incremental steps and the research presented here should facilitate the study in southern California. Later, the models for central California should be improved as well.

## CHAPTER 7: CONCLUSIONS

Data were obtained from seven vernal pool complexes in Sacramento County, California, in order to develop and calibrate ecological models to determine wetland disturbances due to agricultural practices and urban encroachment and to facilitate assessment of wetland functions. Deep ripping vernal pools was considered one of the most destructive types of disturbance because it destroys the duripan or restricting layer so that the vernal pool cannot perform any of the typical vernal pool functions. However, light grazing was considered less destructive than no grazing because of accumulation of organic matter under a no grazing scenario can alter soil texture and thermal characteristics.

A method was developed to quantitatively represent different levels of disturbance and aggregate those measures into a single index from 0.0 to 1.0. This disturbance quotient can be used to rapidly assess the relative condition of vernal pool complexes and could be modified to incorporate variables related specifically to individual pools, such as percent native plant species and maximum pool depth to provide a quick estimate of pool condition. It could not, however, substitute for assessing wetland functions or project impacts.

Numerous topographic characteristics were measured as well as attributes associated with vegetation and soils. However, the percent of native plant species and maximum depth of the vernal pool most closely correlate to disturbance. The close relationship of percent native plant species to disturbance is similar to findings by Hauer et al (in preparation) for depression wetlands in Montana.



A predictive model was developed using discriminant analysis. Results indicated that the disturbance quotient, percent native species, and maximum depth of the vernal pool were the greatest sources of variability and could be used to predict the vernal pool complex in which each vernal pool in the study should occur. Results were accurate for 92.8 percent of the 69 pools examined. Since the vernal pool complexes represented different levels of disturbance, the predictive model may be used to estimate the relative disturbance (condition) of a vernal pool by primarily measuring the three variables.

During the course of data collection, there appeared to be a repeating occurrence of changes in the slope of many vernal pools near their edge depending upon the levels of disturbance. When vernal pools were severely disturbed due to some form of land leveling or deep ripping, the slope within one meter of the edge of the pool was very flat. Undisturbed pools seldom exhibited this flat condition, however. In relatively undisturbed vernal pools, the pool basin was fairly flat but nearly always showed a sharp upturn near the edge. It was often shaped like a saucer. Elevations were computed for vegetation data at one-meter intervals along transects within the pool, but those elevation points did not always fall within the very short distance necessary to compute an reliable correlation between the slope and the disturbance exerted on the pool. Further investigation is needed to compute slope within one meter of the edge of the pool and to measure disturbances within and immediately adjacent to the pool. This author believes that such a study could generate a correlation between certain types of disturbance and slope of the pool edge and that correlation could be useful in assessing project impacts.

**Five wetland functions were identified and models were developed to facilitate assessment of potential project impacts and mitigation requirements. The five functions are: (1) Surface Water Storage in Pool Basin, (2) Subsurface Water Exchange, (3) Maintain Characteristic Habitat for Vernal Pool Vegetation, (4) Maintain Characteristic Habitat for Vernal Pool Invertebrates, and (5) Maintain Characteristic Habitat for Vernal Pool Amphibians. Of these five functions, the first, Surface Water Storage in Pool Basin is the most critical in maintain the viability of the vernal pool. The other functions are largely a consequence of this function. Therefore, efforts should be rigorously enforced to ensure that this function and the variables that influence it are carefully preserved. These functions and their associated models can serve as the foundation for expanding the scope of efforts to assess vernal pool wetlands. Additional functions can be identified in the future and provide an even broader scope of assessment. The Corps of Engineers can use results from this study as the foundation for developing an approach useful in implementing its regulatory role under Section 404 of the Clean Water Act.**

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## APPENDIX A: GLOSSARY

**“A” horizon:** A mineral soil horizon at the soil surface or below an “O” horizon characterized by accumulation of humified organic matter intricately mixed with the mineral fraction.

**Areal cover:** A measure of dominance that defines the degree to which above-ground portions of plants (not limited to those rooted in a sample plot) cover the ground surface. It is possible for the total areal cover in a community to exceed 100 percent because (a) most plant communities consist of two or more vegetative strata; (b) areal cover is estimated by vegetative layer; and foliage within a single layer may overlap.

**Assessment model:** A numeric portrayal of the relationship between ecosystem and landscape scale variables and functional capacity of a wetland. The model is developed and calibrated using reference wetlands from a reference domain.

**Assessment objective:** The reason that wetland functions are being assessed. Assessment objectives normally fall into one of three categories, including: documenting existing wetland conditions, comparing different wetlands at the same point in time (e.g., alternatives analysis), and comparing the same wetland at different points in time (e.g., impact analysis or mitigation success).

**Assessment team (A-Team):** An interdisciplinary group of regional and local scientists responsible for classification of wetlands within a region, identification of reference wetlands, construction of assessment models, definition of reference standards, and calibration of assessment models.

**Available water capacity (available moisture capacity):** The capacity of the soils to hold water available for use by most plants. It is commonly defined as the difference between the amount of soil water at field moisture capacity and the amount at wilting point. It is commonly expressed as inches of water per inch of soil. It is expressed in this dissertation as centimeters of water per centimeter of soil. The capacity, in centimeters, in a 152-centimeter profile or to a limiting layer is expressed as:

Very low	0 to 6.4
Low	6.4 to 12.8
Moderate	12.8 to 19.0
High	19.0 to 25.4
Very high	more than 25.4

**Benchmark:** A fixed, more or less permanent reference point or object, the elevation of which is known. The U.S. Geological Survey (USGS) installs brass caps in bridge abutments or otherwise permanently set benchmarks at convenient locations nationwide. The elevations on these marks are referenced to the National

**Geodetic Vertical Datum (NGVD)**, also commonly known as mean sea level (MSL). Locations of these benchmarks on USGS quadrangle maps are shown as small triangles. However, the benchmarks are sometimes destroyed by construction or vandalism. The existence of any benchmark should be field-verified before planning work that relies on a particular reference point. The USGS and/or local state surveyor's office can provide information on the existence, exact location, and exact elevation of benchmarks.

**Best Management Practices (BMPs)**: Those methods, measures, or practices to eliminate or reduce the introduction of pollutants and their adverse impacts to the aquatic ecosystem. BMPs include structural and nonstructural controls and operation and maintenance procedures.

**Buffer**: The area that surrounds the vernal pool or vernal pool watershed and reduces adverse impacts to vernal pool functions from human activities associated with agricultural, residential, commercial, or recreational development.

**Chiseling**: Tillage with an implement having one or more soil-penetrating points that loosen the subsoil and bring clods to the surface. A form of emergency tillage to control soil blowing.

**Clay**: As a soil separate, the mineral soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

**Claypan**: A very slowly permeable soil with horizons above it. A claypan is commonly hard when dry and plastic or stiff when wet.

**Complex slope**: Irregular or variable slope. Planning or establishing terraces, diversions, and other water-control structures on a complex slope is difficult.

**Direct impacts**: Project impacts that result from direct physical alteration of a wetland, such as the placement of dredged or fill material.

**Direct measure**: A quantitative measure of an assessment model variable.

**Duration** (inundation/soil saturation): The length of time during which water stands at or above the soil surface (inundation), or during which the soil is saturated. As used herein, duration refers to a period during the growing season.

**Duripan**: A duripan (L. *durus*, hard; meaning hardpan) is a subsurface horizon that is cemented by illuvial silica to the degree that less than 50 percent of the volume of air-dry fragments slake in water or during prolonged soaking in acid (HCl). Duripans vary in the degree of cementation by silica. In addition, they commonly contain accessory cements, chiefly calcium carbonate. As a consequence, duripans vary in appearance. They generally are very firm or firmer and are always brittle,

even after prolonged wetting. They grade into and can occur in conjunction with petrocalcic horizons, mostly in semiarid and arid regions. They also grade into noncemented earthy materials and into the fragipans of humid regions. (Soil Survey Staff 1999).

**Dynamic Surface Water Storage:** The capacity of a vernal pool to detain moving water from upgradient water inputs and continuously discharge via overland flow or through hydrologic connections among other vernal pools.

**Flooded:** A condition in which the soil surface is temporarily covered with flowing water from any source, such as streams overflowing their banks, runoff from adjacent or surrounding slopes, inflow from high tides, or any combination of sources.

**Fragipan:** A fragipan (modified from *L. fragilis*, brittle, and pan; meaning brittle pan) is an altered subsurface horizon, 15 cm or more thick, that restricts the entry of water and roots into the soil matrix. It may, but does not necessarily, underlie an argillic, cambic, albic, or spodic horizon. It is commonly within an argillic horizon, but some are within an albic horizon. The fragipan has strongly developed fragic properties (defined below). Commonly, it has a relatively low content of organic matter and a high bulk density relative to the horizons above it. The fragipan has a hard or harder rupture-resistance class when dry. When moist, it has a brittle manner of failure in 60 percent or more of the volume. The term “manner of failure” refers to the tendency of a ped or clod to rupture suddenly rather than to undergo slow deformation when pressure is applied. Air-dried fragments slake when submerged in water. (Soil Survey Staff 1999)

**Frequency (vegetation):** The disturbance of individuals of a species in an area. It is quantitatively expressed as

$$\frac{\text{Number of samples containing species A}}{\text{Total number of samples}} \times 100$$

**Functional assessment:** The process by which the capacity of a wetland to perform a function is measured relative to other wetlands in the same regional wetland subclass. The HGM Approach measures capacity using an assessment model to determine a functional capacity index.

**Functional capacity:** The magnitude at which a wetland ecosystem performs a function. Functional capacity is dictated by characteristics of the wetland ecosystem, the surrounding landscape, and the interaction between the two.

**Functional capacity index (FCI):** An index of the capacity of a wetland to perform a function relative to other wetlands from a regional wetland subclass in a reference domain. Functional capacity indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates that a wetland performs a function at the highest sustainable

functional capacity, the level equivalent to a wetland under reference standard conditions in a reference domain. An index of 0.0 indicates the wetland does not perform the function at a measurable level and will not recover the capacity to perform the function through natural processes.

**Gilgai:** Commonly a succession of microbasins and microknolls in a nearly level area or of microvalleys and microridges parallel with the slope. Typically, the microrelief of Vertisols-clayey soils having a high coefficient of expansion and contraction with changes in moisture content.

**Hardpan:** A hardened or cemented soil horizon, or layer. The soil material is sandy, loamy, or clayey and is cemented by iron oxide, silica, calcium carbonate, or other substance. In this survey area, silica is the dominant cementing agent.

**Heavy grazing:** A comparative term that indicates that the stocking rate of a pasture is relatively greater than that of other pastures. Often erroneously used to mean overuse. cf *light* and *moderate grazing*.

**Highest sustainable functional capacity:** The level of functional capacity achieved across the suite of functions by a wetland under reference standard conditions in a reference domain. The HGM Approach assumes that the highest sustainable functional capacity is achieved when a wetland ecosystem and the surrounding landscape are undisturbed.

**Horizon, soil:** A layer of soil, approximately parallel to the surface, having distinct characteristics produced by soil-forming processes. In the identification of soil horizons, an uppercase letter represents the major horizons. Numbers or lower case letters that follow represent subdivisions of the major horizons. An explanation of the subdivisions is given in the "Soil Survey Manual." The major horizons of mineral soil are as follows:

O horizon- An organic layer of fresh and decaying plant residue.

A horizon- The mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with the mineral material. Also, a plowed surface horizon, most of which was originally part of a B horizon.

E horizon- The mineral horizon in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these.

B horizon- The mineral horizon below an A horizon. The B horizon is in part a layer of transition from the overlying A to the underlying C horizon. The B horizon also has distinctive characteristics, such as (1) accumulation of clay, sesquioxides, humus, or a combination of these; (2) prismatic or blocky structure; (3) redder or browner colors than those in the A horizon; (4) a combination of these.

C horizon- The mineral horizon or layer, excluding indurated bedrock, that is little affected by soil-forming processes and does not have the properties typical of the overlying soil material. The material of a C horizon may be either like or unlike that in which the horizon formed. If the material is known to differ from that in the solum, an Arabic numeral, commonly a 2, precedes the letter C.

**Cr horizon-** Soft, consolidated bedrock beneath the soil.

**R layer-** Consolidated bedrock beneath the soil. The bedrock commonly underlies a C horizon, but it can be directly below an A or a B horizon.

**Hydric soil:** A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation. Hydric soils that occur in areas having positive indicators of hydrophytic vegetation and wetland hydrology are wetland soils.

**Hydrogeomorphic wetland class:** The highest level in the hydrogeomorphic wetland classification. There are five basic hydrogeomorphic wetland classes, including depression, fringe, slope, riverine, and flat.

**Impervious soil:** A soil through which water, air, or roots penetrate slowly or not at all. No soil is absolutely impervious to air and water all the time.

**Importance value:** A quantitative term describing the relative influence of a plant species in a plant community, obtained by summing any combination of relative frequency, relative density, and relative dominance.

**Indicator:** Indicators are observable characteristics that correspond to identifiable variable conditions in a wetland or the surrounding landscape.

**Indirect impacts:** Impacts resulting from a project that occur concurrently, or at some time in the future, away from the point of direct impact. For example, indirect impacts of a project on wildlife can result from an increase in the level of activity in adjacent, newly developed areas, even though the wetland is not physically altered by direct impacts.

**In-kind mitigation:** Mitigation in which lost functional capacity is replaced in a wetland of the same regional wetland subclass.

**Inundation:** A condition in which water from any source temporarily or permanently covers a land surface.

**Jurisdictional wetland:** Areas that meet the soil, vegetation, and hydrologic criteria described in the "Corps of Engineers Wetlands Delineation Manual" (Environmental Laboratory 1987), or its successor.

**Light grazing:** A comparative term that indicates that the stocking rate of one pasture is relatively less than that of other pastures. Often erroneously used to mean underuse. cf *heavy* and *moderate grazing*.

**Long duration:** (flooding)- A flooding class in which the period of inundation for a single event ranges from 7 days to 1 month.

**Mapping unit:** As used in this manual, some common characteristic of soil, vegetation, and/or hydrology that can be shown at the scale of mapping for the defined purpose and objectives of a survey.

**Mineral soil:** A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter usually containing less than 20 percent organic matter.

**Miscellaneous area:** An area that has little or no natural soil and supports little or no vegetation.

**Mitigation:** Restoration or creation of a wetland to replace functional capacity that is lost as a result of project impacts.

**Mitigation plan:** A plan for replacing lost functional capacity resulting from project impacts.

**Mitigation wetland:** A restored or created wetland that serves to replace functional capacity lost as a result of project impacts.

**Model variable:** A characteristic of the wetland ecosystem or surrounding landscape that influences the capacity of a wetland ecosystem to perform a function.

**Moderate grazing:** A comparative term that indicates that the stocking rate of a pasture is between the rates of other pastures. Often erroneously used to mean proper use. cf *heavy* and *moderate grazing*.

**Munsell notation:** A designation of color by degrees of three simple variables-hue, value, and chroma. For example, a notation of 10YR 6/4 is a color with hue of 10YR, value of 6, and chroma of 4.

**Offsite mitigation:** Mitigation that is done at a location physically separated from the site at which the original impacts occurred, possibly in another watershed.

**Out-of-kind mitigation:** Mitigation in which lost functional capacity is replaced in a wetland of a different regional wetland subclass.

**Pan:** A compact, dense layer in a soil that impedes the movement of water and the growth of roots. For example, hardpan, fragipan, claypan, plowpan, and traffic pan.

**Permeability:** The quality of soil that enables water to move downward through the profile. Permeability is measured as the number of inches per hour that water moves downward through the saturated soil. Terms describing permeability are:

Very slow.....less than 0.06 inch

Slow.....0.06 to 0.2 inch

Moderately slow.....0.2 to 0.6 inch



Moderately.....0.6 to 2.0 inches  
Moderately rapid.....2.0 to 6.0 inches  
Rapid.....6.0 to 20 inches  
Very rapid.....more that 20 inches

**Phase, soil:** A subdivision of a soil series based on features that affect its use and management. For example, slope, stoniness, and thickness.

**Plant community:** All plant populations occurring in a shared habitat or environment.

**Plant cover:** See areal cover.

**Ponded:** Standing water on soils in closed depressions. Unless the soils are artificially drained, the water can be removed only by percolation or evapotranspiration.

**Poorly drained:** Soils that commonly are wet at or near the surface during a sufficient part of the year that field crops cannot be grown under natural conditions. Poorly drained conditions are caused by a saturated zone, a layer with low hydraulic conductivity, seepage, or a combination of these conditions.

**Profile, soil:** A vertical section of the soil extending through all its horizons and into the parent material.

**Project alternative(s):** Different ways in which a given project can be accomplished. Alternatives may vary in terms of project location, design, method of construction, amount of fill required, and other ways.

**Reference domain:** The geographic area from which reference wetlands are selected. A reference domain may, or may not, include the entire geographic area in which a regional wetland subclass occurs.

**Reference standards:** Conditions exhibited by a group of reference wetlands that correspond to the highest level of functional capacity (highest, sustainable level of functioning) across the suite of functions performed by the regional wetland subclass. The highest level of functional capacity is assigned an index value of 1.0 by definition.

**Reference wetlands:** Wetland sites that encompass the variability of a regional wetland subclass in a reference domain. Reference wetlands are used to establish the range of conditions for construction and calibration of functional indices and establish reference standards.

**Region:** A geographic area that is relatively homogeneous with respect to large-scale factors such as climate and geology that may influence how wetlands function.

**Regional wetland subclass:** Wetlands within a region that are similar, based on hydrogeomorphic classification factors. More than one regional wetland subclass may be identified within each hydrogeomorphic wetland class, depending on the diversity of wetlands in a region and the assessment objectives.

**Shrink-swell:** The shrinking of soil when dry and the swelling when wet. Shrinking and swelling can damage roads, dams, building foundations, and other structures, as well as plant roots.

**Soil horizon:** A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics (e.g., color, structure, texture, etc.).

**Soil permeability:** The ease with which gases, liquids, or plant roots penetrate or pass through a soil layer.

**Soil profile:** A vertical section of a soil through all its horizons and extending into the parent material.

**Soil series:** A group of soils that have profiles that are almost alike, except for differences in texture of the surface layer or of the underlying material. All the soils of a series have horizons that are similar in composition, thickness, and arrangement.

**Soil texture:** The relative proportions of the various sizes of particles in a soil.

**Substrate:** The base or substance on which an attached species is growing.

**Subsoiling:** Tilling a soil below normal plow depth, ordinarily to shatter a hardpan or claypan.

**Swale:** A surface feature connecting two or more adjacent vernal pools. Swales can convey concentrated surface flow during high-water events, but lack a bed and bank (e.g., an undefined drainage).

**Topography:** The configuration of a surface, including its relief and the position of its natural and man-made features.

**Transect:** As used herein, a line on the ground along which observations are made at some interval.

**Upland:** The non-wetland area upgradient of the vernal pool margin that comprises the intervening non-vernal pool terrain.

**Value of wetland function:** The relative importance of a wetland function to an individual or group.

**Variable:** An attribute or characteristic of a wetland ecosystem or the surrounding landscape that influences the capacity of the wetland to perform a function.

**Variable index:** A measure of how an assessment model variable in a wetland compares to the reference standards of a regional wetland subclass in a reference domain.

**Vernal pool:** A seasonal wetland that forms in depressions as a result of a shallow, relatively impermeable soil layer that restricts downward movement of water. Vernal pools result from an unusual combination of soil conditions, Mediterranean climate, topography, and hydrology and support a specialized biota containing an abundance of threatened and endangered species.

**Vernal pool complex:** A set of naturally occurring vernal pools in close proximity, often within the same watershed.

**Very long duration (flooding):** A duration class in which the length of a single inundation event is greater than 1 month.

**Watershed:** An area in which water drains to a common outlet. The size of the catchment basin will vary depending on the scale within which a particular function is performed.

**Wetland:** See **Wetland ecosystem**.

**Wetland creation:** The process of creating a wetland in a location where a wetland did not previously exist. Wetland creation is typically performed as a means to try to satisfy mitigation requirements.

**Wetland ecosystems:** In 404: ".....areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (Corps Regulation 33 CFR 328.3 and EPA Regulations 40 CFR 230.3). In a more general sense, wetland ecosystems are three-dimensional segments of the natural world. They occur where the presence of water, at or near the surface, creates conditions leading to the development of redoxomorphic soil conditions, and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

**Wetland enhancement:** The process of increasing the capacity of a wetland to perform one or more functions. Wetland enhancement can increase functional capacity to levels greater than the highest sustainable functional capacity achieved under reference standard conditions, but usually at the expense of sustainability, or with a reduction in functional capacity of other functions. Wetland enhancement is typically done for mitigation.

**Wetland functions:** The normal activities or actions that occur in wetland ecosystems, or simply, the things that wetlands do. Wetland functions result directly from the characteristics of a wetland ecosystem and the surrounding landscape and their interaction.

**Wetland mitigation banking:** The process of creating a "bank" of created, enhanced, or restored wetlands to serve at a future date as mitigation for project impacts.

**Wetland restoration:** The process of restoring wetland function in a degraded wetland. Restoration is typically done as mitigation.

**Wetland values:** See **Value of wetland functions**.

**Wilting point (or permanent wilting point):** The moisture content of soil, on an oven-dry basis, at which a plant (specifically a sunflower) wilts so much that it does not recover when placed in a humid, dark chamber.

## **APPENDIX B: THE HYDROGEOMORPHIC APPROACH: IMPLEMENTATION AND POTENTIAL USES**

The Hydrogeomorphic Approach for wetland assessment is implemented in two phases. During the Development Phase, an interagency, interdisciplinary team of wetland scientists construct assessment models and develop a regional guidebook for a particular type of wetland in a particular geographic area. During the Application Phase, individuals, primarily regulatory personnel and private consultants will utilize the assessment models in the regional guidebook to assess potential project impacts, determine mitigation requirements, and assess mitigation success. A more detailed description of each phase and potential uses and limitations of the HGM Approach are provided below.

### **Development Phase**

An interagency, interdisciplinary assessment team of wetland experts, or an A-Team, conducts the Development Phase. The A-Team initially classifies wetlands into different wetland subclasses based on hydrogeomorphic factors (Brinson 1993). For each regional subclass, the A-Team develops a narrative profile describing the wetland's physical, chemical, and biological attributes (see Chapter 3). The profile also includes the functions likely performed by the regional wetland subclass as determined by experience and technical expertise of the A-Team and from published literature. The A-Team then defines each function, identifies and defines variables related to each function, and illustrates the relationship between functions and variables in assessment models. The A-Team then gathers data from reference wetlands, calibrates the revised models, and field

tests the calibrated models. These models define the relationship between attributes and processes of the wetland ecosystem and surrounding landscape and the capacity of a wetland to perform a function. Application of the assessment model results is presented as a functional capacity index (FCI) with a range of 0.0-1.0. The FCI is an index of the capacity of a wetland to perform a function relative to other wetlands from the same regional subclass in the reference domain. The standard of comparison used to scale functional indices are reference standards, or the conditions under which the highest sustainable level of function is achieved across a suite of functions performed by reference standard wetlands in a regional wetland subclass, as briefly discussed above. A calibrated draft regional guidebook is then prepared and, after additional peer review, revised and published as an Operation Draft Regional Guidebook (ODRG). The ODRG is then used during the application phase by regulators, planners, and others who require assessment of wetland ecosystems.

The Development Phase of the HGM Approach is implemented by completing nine steps or tasks (Clairain and Smith, in preparation). These tasks are not mutually exclusive nor are they carried out solely in sequence. Development of regional guidebooks is an iterative process often requiring examination of information developed during prior tasks and then revising information in subsequent tasks as a result of new data or literature. For example, an A-Team may classify the different wetland subclasses during Task II based on the experience of the A-Team members but may find that classification should be revised after data collection during Task V. There is, however, a logical progression in the

Development Phase from formation of an A-Team that develops the regional guidebook to eventual publication as an operational draft.

### **Application Phase**

After completion of the development phase, the Application Phase of the HGM Approach is implemented, at which time the assessment models are used to assess wetland functions. The Application Phase of the HGM Approach, like the Development Phase, also requires several steps for completion. The assessment procedure includes a characterization of the wetland, assessment of projected site characteristics if project impacts are considered, and analysis of the assessment results.

### **Potential Uses**

The HGM Approach is a tool to rapidly and accurately determine the level of environmental impacts of proposed projects, compare project alternatives, identify measures that would minimize environmental impacts, determine mitigation requirements, and establish criteria for measuring mitigation success. Models can be applied to assess pre-project conditions, determine impacts of project alternatives, and design mitigation options to minimize impacts of potential project scenarios. Application of the models to project future conditions must be performed cautiously. A short description of potential uses of the HGM Approach is provided below.

#### **Assessment of Pre-Project Conditions**

During pre-project conditions, the functional capacity of a wetland area can be determined by applying the models and calculating the index. Once the index is

determined, it can be multiplied by the wetland size to determine the functional units provided by the wetland. This application is similar to the procedures applied in the Habitat Evaluation Procedures of the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 1980, 1981) to compute habitat units. Functional capacity units can be compared between similar wetland subclasses in similar geographic areas to establish priorities for project planning and selection of alternatives. Those wetlands determined to have the greatest functional capacity may be avoided while those with low (but above 0.0) functional capacity may be targeted for restoration or enhancement as options in mitigation alternatives.

### **Assessment of Project Impacts**

Once functional capacity units have been determined for pre-project conditions, the functional capacity can be calculated after project implementation by running the models under anticipated conditions. For example, if the flooding regime of the wetland occurs on an annual frequency before the project, the model is run using that flood frequency. However, if it is anticipated that the flooding regime will change and only occur once every five years, then the model can be run under this scenario with expected changes in other variables to provide a measure of the projected functional capacity during post-project conditions. Multiplying the index multiplied by the wetland size will provide a measure of the project impacts when compared to pre-project model results. Both direct and indirect impacts can be calculated in this manner by calculating different indices and different areas of the wetland impacted directly and indirectly.



## Design of Mitigation Alternatives

Since the models consist of certain combinations of wetland characteristics expected to provide certain wetland functions, creating those sets of characteristics should result in replacement of functions. Therefore, the models can be used to establish mitigation design criteria and, if properly reproduced, increase the likelihood for replacement of functions. One must recognize, however, that some criteria may be very difficult to replace. Replacement of large timber for production of mast-bearing trees to provide nesting cavities for selected wildlife species may be necessary to replace a particular wetland function, but may be very difficult and require many years to achieve in a cost-effective manner.

**APPENDIX C: PEER REVIEW WORKSHOP  
HELD MAY 21-23, 1996  
IN  
DAVIS, CALIFORNIA:  
AGENDA AND  
LIST OF PARTICIPANTS**

**U.S. Army Corps of Engineers, Sacramento District  
Wetland Functional Assessment Models for Vernal Pools  
The Hydrogeomorphic Approach**

**WORKSHOP AGENDA  
Natural Resources Conservation Service  
Davis, California  
May 21-23, 1996**

<b>Tuesday</b>		
<b>8:00- 8:30</b>	<b>Introduction of Workshop</b>	<b>EC Staff</b>
<b>8:30-11:00</b>	<b>Hydrogeographic Functional Assessment oversight</b>	<b>Clairain, WES</b>
<b>11:00-11:30</b>	<b>Purpose &amp; duties of Vernal Pool Assessment Team (A-team)</b>	<b>Vinzant, COE</b>
<b>11:30-12:00</b>	<b>Introduction of Models</b>	<b>"A" Team Members</b>
<b>12:00- 1:30</b>	<b>Lunch-on your own in nearby Davis</b>	
<b>1:30- 2:00</b>	<b>Final designation of model review groups and direction</b>	<b>EC Staff</b>
<b>2:00- 4:30</b>	<b>Model review teams-familiarization with draft functional models</b>	<b>Break-out rooms oversight by Clairain and EC Staff</b>

<b>Wednesday</b>		
<b>8:00- 8:30</b>	<b>Description of Jepson Prairie Vernal Pools</b>	<b>Cal F&amp;G/TNC</b>
<b>8:30- 9:00</b>	<b>Instructions for Field Exercise</b>	<b>EC Staff</b>
<b>9:15- 9:30</b>	<b>Break</b>	
<b>9:30-10:00</b>	<b>Travel to Jepson Prairie (23 miles from NRCS office)</b>	
<b>10:00-12:00</b>	<b>Review teams apply models to Jepson Prairie Vernal Pools</b>	<b>EC Staff</b>
<b>12:00- 1:00</b>	<b>Lunch-Box lunches provided</b>	
<b>1:00- 4:00</b>	<b>Review teams apply models (continued) to Jepson Prairie Vernal Pools</b>	<b>EC Staff</b>
<b>4:00- 4:30</b>	<b>Return to Davis*</b>	
<b>*until 8:00</b>	<b>Experience Davis Farmers market (optional)</b>	
<b>Thursday</b>		
<b>8:00- 8:30</b>	<b>Observation of field exercises</b>	<b>EC Staff</b>
<b>8:30-11:30</b>	<b>Review teams finalize comments for afternoon presentation (breakout rooms)</b>	<b>EC Staff</b>
<b>11:30- 1:00</b>	<b>Lunch-on your own in nearby Davis</b>	
<b>1:00- 2:30</b>	<b>Review teams presentation</b>	<b>EC Staff</b>
<b>2:30- 3:00</b>	<b>Overview &amp; next step</b>	<b>EC Staff, Vinzant</b>

**Wetland Functional Assessment Models for Vernal Pools:  
The HGM Approach  
May 21-23, 1996**

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## VITA

Ellis Joseph Clairain, Jr., was born January 22, 1949, in Bogalousa, Louisiana, the son of Ellis and Ethel Clairain. He attended Covington High School, graduating in May 1967. He entered Louisiana State University (LSU) in the fall of 1967. In August 1970 he married his high school sweetheart, the former Janice Cheryl Hill (Sherry), and they had their first child, Jay Michael, August 9<sup>th</sup>, 1972. Mr. Clairain earned a bachelor of science degree in forestry with a minor in wildlife biology in 1971. He continued studies at LSU and obtained a master of science degree in fisheries science with minor in experimental statistics in 1974.

He worked for an environmental consulting firm in Pine Bluff, Arkansas, and New Orleans, Louisiana, through most of 1975 before being hired as an Environmental Specialist with the U.S. Army Corps of Engineers (CE) District, Vicksburg, Mississippi. While at the Corps District office, he was responsible for preparation of environmental impact statements and coordination between the Environmental Branch and the Permits Branch.

In September 1975 the U.S. Army Engineer Waterways Experiment Station (WES) hired Mr. Clairain as a Biologist with the Wetlands and Terrestrial Habitat Group. WES is also located in Vicksburg, Mississippi, and was one of four Corps of Engineers research laboratories in the nation. On November 30, 1976, Jay was joined by little sister Lindsay Robin and on February 25, 1978, both gained a little sister, Sara Brooke.

While at WES, Mr. Clairain has taught numerous courses on wetland delineation and evaluation procedures including a three-week course on wetland

assessment in the Republic of China. He has served as Chief of the Wetlands Branch at WES and is responsible for managing an interdisciplinary team of scientists responsible for conducting national research focusing on delineation of wetland boundaries, evaluation of wetland functions and their values, and restoration and creation of wetland habitats. The Branch was responsible for developing the *Corps of Engineers Wetlands Delineation Manual*, the *Wetland Evaluation Technique* or WET, and *An Approach for Assessing Wetland Functions using the Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices*. The Branch is also responsible for a significant proportion of all CE training in delineation and evaluation and in 1996 provided instruction to approximately 350 students at training locations throughout the United States.

Mr. Clairain also served as the Task Area Manager for the Delineation and Evaluation Project under the CE's Wetlands Research Program from 1990 - 1995. In this capacity he was responsible for designing and directing research studies focusing on improving wetland delineation procedures and techniques to evaluate wetland functions and values such as the HGM approach to wetland assessment, which was developed in his task area.

Mr. Clairain is currently Leader of the Wetlands Research Team and is responsible for directing further development and implementation of the HGM approach to wetland assessment. Approximately 15 different regional guidebooks are under development around the country as part of this effort. Mr. Clairain is responsible for coordinating research efforts for all of the regional guidebooks and directly responsible for two guidebooks in Florida, two in Alaska, one in California, one in



Illinois, and four in the Northern Rocky Mountain region. He also teaches a one-day Executive Course on the HGM Approach and a five-day Wetland Assessment Course on application of the HGM Approach.

He has published numerous technical articles and made both national and international presentations. He is a Certified Fisheries Scientist with the American Fisheries Society and a Certified Professional Wetland Scientist with the Society of Wetland Scientists and has served as the chair for that organization's national meeting in 1987. He is also a member of the Wildlife Society and Sigma Xi – A National Research Society.

# DOCTORAL EXAMINATION AND DISSERTATION REPORT

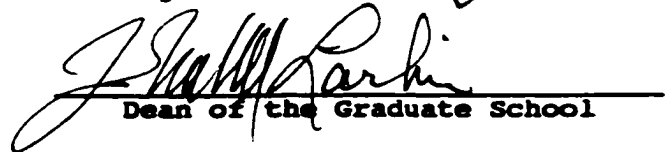
**Candidate:** Ellis J. Clairain, Jr.

**Major Field:** Oceanography and Coastal Sciences


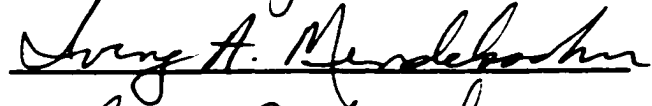
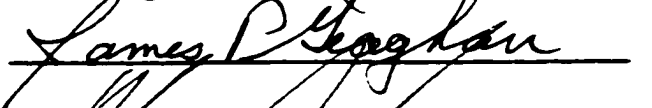
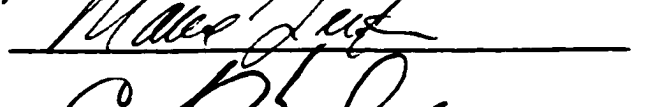
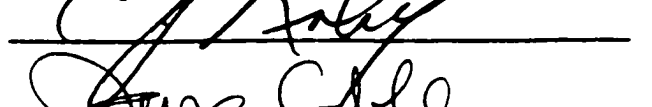
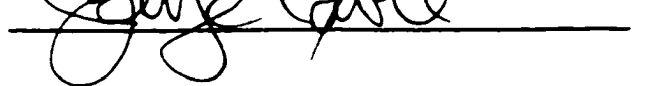
**Title of Dissertation:** Ecological Models for Assessing Functions of Hard Claypan Vernal Pool Wetlands in the Central Valley of California Using the Hydrogeomorphic (HGM) Approach for Wetland Assessment

**Approved:**

  
Major Professor and Chairman

  
Dean of the Graduate School

## EXAMINING COMMITTEE:

**Date of Examination:**

April 5, 2000